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LABORATORY METHODS IN PHYSICS FOR THE BLIND.

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THE PAPER DESCRIBES AUDITORY AND TACTILE ADAPTATION OF PHYSICS LABORATORY APPARATUS FOR USE BY BLIND STUDENTS, TOGETHER WITH FIVE METHODS OF DRAWING RAISED LINE AND INDENTED DIAGRAMS FOR USE IN PHYSICS EXPERIMENTS. A SURVEY OF PHYSICS LABORATORY METHODS IN SCHOOLS FOR THE BLIND IN THE UNITED STATES AND SEVEN FOREIGN COUNTRIES, AND TWO SIMPLE PHYSICS EXPERIMENTS FOR BLIND HIGH SCHOOL STUDENTS, ARE INCLUDED. (KH)

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LABORATORY METHODS IN PHYSICS FOR THE BLIND

By

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LABORATORY METHODS IN PHYSICS FOR THE BLIND

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ABSTRACT

There are two major problems which confront the blind student of physics: a difficulty in reading the abundance of material, particularly at the college and graduate school level, and a difficulty with laboratory work. This paper deals with this latter problem in detail, not setting forth a pat solution, but setting forth ways in which laboratory work can be made easier to the blind student. The experiments described here have been adapted for blind students, but they may be useful to sighted students as well.

The principles of tactification (producing the experiment's output in the form of tactile sensation), audification (producing audible output) and magnification of braille scales are set forth with historical accounts of how these principles were employed. The use of quite simple electronics for aid in laboratory work will be detailed and a chapter will describe the uses to the blind of the simple R.C. oscillator circuit, not only in physics, but outside the field as well. A final chapter is a brief and inconclusive survey of laboratory methods for the blind in other countries.

FOREWORD

The writer wishes to express his sincere gratitude to Mr. A. Wexler of Melbourne, Australia several of whose works have been used extensively in this paper and without whose kind advice this paper would not have been possible. He is also grateful to Dr. Myron P. Garfunkel of the University of Pittsburgh who has given much helpful advice and encouragement; to his mother, Lois T. Henderson, who spent long hours reading the paper to him for the sake of revision; and to his father, Mr. Albert J. Henderson, who aided in the preparation of several of the schematic diagrams. Finally, to all those too numerous to mention by name here, through whose kindness the study of physics has been possible for him and other blind physics students, the writer expresses his gratitude and appreciation.

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I. INTRODUCTION

The path of the blind student of science seems at first glance so strewn with apparently insurmountable obstacles that the question is often asked: Why teach science at all, and especially physics, to the blind?

There are several reasons why the blind should study, not just be acquainted with, science. The first reason is that many blind students have a desire to do so. Blindness is a condition of the eyes, not of the mind. Intelligent blind people, as well as all others with intelligence, are curious. Curiosity is also the driving force of the scientist. Therefore, the blind student who is curious may make as good a science student as any curious sighted student and possibly a better one than many sighted students who are required to take a science course or are in the course for reasons other than a willingness to learn.

Second, the blind person, as well as anyone else for that matter, should have an acquaintance with the scientific method. In one respect, this is more important for the blind than for the sighted. One objective of the scientific method is to cause one to be rigorously observant. It is commonly believed that the other four senses of a blind person are automatically better than those in sighted people. This is not true. The blind learn to use these other senses to greater advantage, and this sharper use of the senses possessed by the blind helps them become more mobile and to avoid possible dangers. But we are speaking here about educational experiences on a higher level than the mere avoidance of a hot stove. It is the rigorous training to observe demanded by the scientific method that gives these more abstract experiences educational significance. Because the information input of the blind is limited due to lack of sight, there is a greater probability that the received information may lead to false conclusions unless this objective method of thinking is employed.

Third, our society is becoming constantly more technically oriented and technology is based upon the discoveries of science. The world of the physicist is perhaps more prevalently observable in our technology than that of any other scientist. Terms such as "thrust" and "g force" are being commonly used now, and the blind as well as the sighted should have an understanding of them. The blind can be taught to understand these terms and the basic rules which make our technology possible through the study of physics.

The fourth reason is of special significance to the blind. From the study of optics, he can gain a knowledge of the very thing that seems to elude him and make his life impossible - light. He may never be able to comprehend visual beauty, but he can understand the laws of propagation, reflection, refraction and polarization. He can, in other words, gain the physicist's knowledge of light. This is not the same knowledge as that of his sighted counterpart, but it is better than no knowledge of light at all.

The fact that the world of the blind is unseen should in one way make him a better student of physics. Since he cannot see his environment, he has become used to comprehending that which he cannot see and so such things as the nucleus of the atom or a train of sound waves will not necessarily be difficult for him to comprehend.

But just stating reasons why the blind should study science does not make the difficulties any less formidable. Of the many input channels to the brain, vision seems to be most important. Optic nerve endings account for sixty five percent of all afferent neurons in man, as opposed to only two percent being accounted for by auditory nerve endings.[1] Ninety percent of all sense impressions come through the eye.[2] This would seem to give credence to the doubts in the minds of many teachers and professors regarding the inability of the blind to study science.

There are really only two major problems that confront the blind students of physics. The first is the difficulty in reading an ever-increasing amount of material which is constantly being published. This problem of reading, the solution of which may one day be achieved by the development of the electronic reading devices and computer programs designed to convert printed material into synthetic speech, would itself fill a good sized volume. (And other problems, such as comprehending blackboard diagrams and doing homework can be solved by the student's willingness to put long hours of work into his study and by his possession of a slightly over-aggressive personality which would enable him to ask the teacher to say aloud what is being written on the blackboard.)

However, this paper will concern itself only with the second major problem of the blind in the study of physics - the difficulty of participating in laboratory work. This paper will not attempt to supply all the answers to problems which may come up in different kinds of laboratory work. The student who intends to perform experiments or the blind person who wishes to work in an industrial laboratory will still have to possess the

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[1] Bennett, Degan and Spiegel, HUMAN FACTORS IN TECHNOLOGY, p. 295

[2] Demal, F., "Zurpraxis des Tastens", ZEITSCHRIFT FUR DAS OSTERREICHISCHE BLINDENWESEN, Vol. 8, 1921, p. 1,449.

utmost ingenuity. The qualities set forth by Dr. C. M. Witcher in his article on laboratory work for the blind "...above average intelligence, above average manual dexterity ... and aggressive personality"[3] will still be necessary.

One of the first questions asked by the physics teacher with a blind student or by the employer in industry considering a blind applicant is "Can he do laboratory work?" Both the sighted and the blind may be inclined to consider the problem involved too great and to answer this question for themselves in the negative. As a matter of fact, early writers[4] on the subject considered advanced laboratory work impossible. B. B. Ballard, in his article "The Physical Sciences in the Junior High School" states: "It is obvious that no person without sight should pretend to claim laboratory credit in college, where the reading of many delicate instruments is necessary..."

However the early writers did recognize the need for simple experiments to demonstrate certain concepts to beginning students. To several blind physicists and technicians who have been successful with modern laboratory work, this would seem childishly elementary, but it was at least a step in the right direction. It was not until the publication in 1961 of Mr. A. Wexler's monograph "Experimental Science for the Blind, an Instruction Manual Based on a Variety of Devices" that any significant work was made public concerning experimental equipment for the blind,

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[3] Zahl, P. A., BLINDNESS: MODERN APPROACHES TO THE UNSEEN ENVIRONMENT, p.253.

[4] Ballard, B. B., "The Physical Sciences in the Junior High School", PROCEEDINGS FOR AMERICAN ASSOCIATION OF INSTRUCTORS FOR THE BLIND, 1938, p. 188.

although electronic devices aiding the blind in making electrical measurements were being developed as early as 1947. This monograph has been used extensively as source material for this paper.

Why should the blind do laboratory work? Again, there are several reasons. In the first place, they enjoy it. In the elementary grades, qualitative experiments or demonstrations are enjoyed by blind students in the normal way of all children. Also, as mentioned above, the blind are curious. Even though he cannot see the world about him, he wants to know about it in terms he can understand. The purpose of really meaningful experimentation is observation and measurement, and this the blind person must do if he is to learn about his world.

It was mentioned above that because the world of the blind is unseen he would have no trouble bridging the gap between the concrete and the abstract which is unseen in the sighted world. This is true only if the blind student has a full comprehension of the concrete first. The aforementioned example of light is again a good illustration here. Although the blind student can comprehend the physical properties of light, associating it with other electromagnetic radiation, he can do so easily only after having experienced its presence. To the sighted person, this is easy. His daily existence depends upon the presence of light, and this is taken for grated. For the blind, it is another matter. One method of introducing a blind student to light is to use a common incandescent lamp and a device which clicks or hums with increasing frequency with increasing intensity of light. He can be asked to aim the device at the lamp. He notices an increase in the frequency of clicks. The lamp is turned on and off, and the frequency varies accordingly. He turns the probe away from the lamp and the frequency drops. Since the blind student is probably familiar with the heat produced by the bulb, it now becomes necessary to demonstrate that it is not only the heat which causes the increased frequency of clicks. The lamp is turned off, and the student is told to turn the probe toward a window. He notices an increase in click frequency. A hand or sheet of dark paper is placed in front of the probe and the clicks cease. With demonstrations of this type, he gains a familiarity with light. From here he can progress to optics experiments using the same probe and experience first hand the laws of reflection and refraction.

Dr. D. W. Hamilton[5] has argued that because of the difficulties involved with experiments, first hand knowledge of the phenomenon is not necessary. According to the argument, the experiment when performed by the student is quite often in error, and the "fudge factor" is common in student-performed experiments. Therefore, the argument continues, it will be as useful to the blind student if the teacher does the experiment. One fallacy of this argument is that the only experiment certain to be free of mishap is the demonstration practiced beforehand by the teacher.

It is also believed that because so much experimental work depends upon sight, it would be impossible for blind students. Yet because this lack of sight prevents the blind student from obtaining much accurate information, he should attempt experimental work, and methods have been devised which make this possible.

The experiments used to illustrate the remainder of this text are those of elementary physics rather than more advanced work. At the advanced level, the gap between the concrete and abstract has already been

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[5] Hamilton, D. W. "Proceedings of American Association for Instructors for the Blind", 1932, p. 775.

bridged. A stream of "particles", for example, appears to the experimenter as a trace on an oscilloscope or a reading on an ammeter. No further abstraction need be made for the blind experimenter if this stream of particles should be apparent as a tone in an earphone. At the elementary level, however, this gap has yet to be bridged. And it is here that a great deal of ingenuity is demanded on the part of the teacher to make certain abstract concepts of physics meaningful to the student not only through lecturing but through a laboratory period in which the student performs experiments linking these concepts with events in the concrete world.

It is the hope of the writer that by presenting this case for the blind laboratory worker and by compiling information about many devices which enable the blind to perform experiments independently, he may do three things. First, he may acquaint associations and institutions for the blind who either teach classes of blind students or provide itinerate teachers for the individual blind student in public school with descriptions and drawings of the already existing devices. Second, he hopes to encourage blind students who are capable to make every effort to study as much physics as their sighted counterparts. And third, he hopes that by presenting the basic principles of adaptation for the blind he might encourage the development of new and better devices, methods and attitudes.

II. DIAGRAMS, MODELS, GRAPHS AND THE TACTILIZATION OF EXPERIMENT OUTPUT

In a class of sighted students, diagrams of apparatus are used constantly. Even in the class of blind students it may be more feasible, or at least quicker, to draw a diagram rather than to set up the apparatus. This will, of course, require drawings that the blind can "see".

For truly successful drawings for the blind, there are certain criteria. A material should be used which is easily obtainable, from which the lines can be easily erased, and upon which diagrams can be easily and quickly duplicated. Moreover, the lines should appear in a raised form because indentions are not as obvious to the finger tips. Unfortunately, some methods of diagramming are good for one use and poor in another situation. The blind experimenter usually uses a variety of the methods to be discussed and often he must improvise to obtain the desired results.

A. Materials and Methods of Raised-line Diagrams

There are five ways in which raised or indented line drawings can be formed. They can be etched or cut into the material. An early example of this was described in the 1774 issue of "The Edinburgh Review" when an anonymous blind writer described a board constructed with a high lip around the edge and filled with wax upon which it would be possible to write with a sharp instrument.[6] The best material for this sort of diagram is wax, plasticine or the like. These are easily available and they can also be easily erased with a spatula or knife, a characteristic which is essential

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[6] Zahl, P. A., BLINDNESS: MODERN APPROACHES TO THE UNSEEN ENVIRONMENT, p. 406.

in the case where the student is doing his own diagramming. These drawings cannot, of course, be kept in a notebook or textbook which is their main disadvantage. Wexler has partially solved this problem by impregnating cardboard with a microcrystaline wax.[7] He uses this type of wax rather than parafin because of its hardness. It will produce a firmer line. Other disadvantages than the difficulty of storing are its inaccessability and the fact that it does not create a raised line.

The lines of the diagram can also be indented into a medium which is backed with a soft material such as thick felt or rubber, into which the drawing utensil can sink. For example, a piece of Braille paper is placed on a blotter and drawn upon with a toothed wheel in the end of a long stylus. The paper is pushed into the blotter, thus making a raised line on the underside of the paper. The indented line on the upper side is too narrow to be distinguished with the fingers which means that the diagram must be drawn backwards, and this is its greatest disadvantage.

The tracing wheel method mentioned above is excellent for textbook use. The diagram is penciled backwards and then traced with the tracing wheel. When the paper is turned over, the drawing appears as a raised line, and its various parts can be labeled in Braille. The tracing wheel gives a serrated line, whereas a stylus would give a smooth line. Combinations of these two kinds of line can be used to indicate different parts of the diagram. Wexler uses aluminium foil about 0.08 cm thick as a drawing medium and a pencil or other blunt pointed object as a

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[7] Wexler, A., Lecture to the Convention of the Association of Japanese Teachers of the Blind held in Kyoto, July, 1964.

drawing instrument. In this case, the indentation is actually wide enough to be used by the student as a reference while drawing the diagram. But for purposes of study, the diagram again must be drawn backwards.

A third method is to use resilliant backing (such as hard rubber), a thin plastic or celophane medium, and a ball point pen as a drawing instrument. A raised line appears directly behind the pen. The physics of this process is not fully understood, but it seems that the pressure of the pen imparts enough elastic energy to the rubber so that the plastic or celophane continues to move through the central position and pop out into a "wrinkle" or raised line. A board employing this principle has been manufactured for some time by the American Foundation for the Blind in New York. Called the Sewall Embossing Board, it is a plywood board 17 cm wide by 27 cm long, covered by a 1 cm thick sheet of elastic rubber which is, in turn, coated with a fine powder such as cornstarch to prevent friction between the rubber and drawing medium, in this case 0.05 mm thick plastic. This is by far the easiest method of diagramming available in spite of the fact that erasures cannot be made and there is a possibility of puncturing or tearing the thin sheets in the drawing process. There is a tendency to wrinkle, so the sheets must be attached to cardboard for preservation in a notebook. If a ball point pen containing ink is used (this is not necessary to simply create the raised lines), the drawings can be shared with sighted students or workers. The plastic obtainable through the Foundation for the Blind is less inclined to tear than household celophane; however, the celophane is more readily accessable.

The fourth method of forming diagrams is to lay the line on the writing surface. The earliest implement of this type was a wax pencil or crayon developed by Mirza Rezi, a Persian, in the seventeenth century.[8] A modern adaptation of this method is Relievo, a thick, sticky ink contained in a tube with a ballpoint tip which can be spread on any surface and is distinguishable to the fingers. If, however, the paint oozes out on both sides of the ball, the line becomes broad and indistinct. This can be remedied by texturing the paint with glass beads or pieces of rayon flak.[9]

Another device which employs the same method of drawing is the tape pen. This consists of two main parts - the inner cartridge and the outer body of the pen. The inner cartridge contains a roll of tape ranging from 0.3 cm to 0.03 cm in width, and a plastic channel which serves as a guide for the tape. At the end of the channel is a small roller. At the end of the outer pen is another roller which engages this smaller roller to aid the tape in being paid out. As one draws with the pen, the tape is paid out in a line and adheres to the surface upon which the drawing is done. The tip of the outer pen is also equipped with a small knife blade. When the teacher or student drawing the diagram wishes to start a new line, he backtracks over the laid tape to the end point of the last line he has just drawn and presses the blade against the tape, cutting it off there. He then starts the tape over the roller and begins again. The bottom roller, in the form of a caster with a groove in the middle to help hold the tape in place, is free to rotate, thus making it easier to draw or construct circles or other curves. The circumference of the pen tip is

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[8] *Ibid.*, p. 391.

[9] *Ibid.*, p. 409.

also slotted, and a latch on the end caster can be slipped up into one of these slots to hold it stationary for straight line drawings. This is used best by a teacher or laboratory assistant who wishes to draw a diagram for the blind student or worker. Because of the several thicknesses of tape available, a variety of line textures may be had. The tape will adhere to any slightly rough or porous surface, and erasure is made by simply pulling the tape from the surface.

According to the writer's present information, this pen is available only through the Brady Tape Manufacturing Company, along with the type of tape used, thus making it unavailable for use unless ordered in advance. It is not impossible for the blind student wishing to draw a diagram to use a tape pen, but its use is so laborious and frustrating as to make it impractical for this use. In the first place, loading is extremely difficult for a blind worker with the present design, since in pushing the cartridge into the pen body, the end of the tape protruding below the cartridge may adhere to the side of the tube, or it may knot up in some other way, thus preventing its protrusion through the bottom of the pen, and loading must be repeated. This difficulty is somewhat lessened by placing a bolt or short piece of wire to the end of the tape, thus applying a gravitational tension which will keep the tape straight and away from the sides of the tube. The best type of weight for this use is wire, as it will fit more easily through the end of the pen. However, this involves keeping track of one more item of equipment, and a small one at that, and in experimental work, especially when the experiment is in full swing, this "housekeeping" should be kept to a minimum.[10]

Another method of laying a raised line on paper, developed in the Netherlands, consists in writing with a pen filled with a certain chemical upon a paper impregnated with another chemical, the reaction of which causes a raised line to appear. Unfortunately, insufficient information about this process has been gathered to make a true evaluation. This appears to be a step in the right direction. The drawing medium is ever-available paper, and unless the two chemicals are rare, they will be as available as ordinary ink. However, according to present information, it takes a minute or two for the line to set firmly enought to be felt, which would mean a longer time taken in doing diagrams, although drawing itself would be extremely easy. Also, by having several inkwells with varous concentrations of one of the reactants, it would be possible to create several line thicknesses.

The fifth method of forming diagrams is to construct the line with thread, wire, or spring steel, strung between pins imbedded in a soft matrix, or, in the case of a method developed by Nicholas Saunderson, a blind mathematician, between pegs in a pegboard.[11] This method lends itself best to geometrical construction and graphs. However, since graphs are at times the most expedient way to express experimental results, this method may be of great use to the blind physics student.

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[10] In fact, Wexler makes a point of this by using a spring balance for weighing rather than a modified pan balance, in order to prevent the student from having to keep track of the weights.

[11] Zahl, P. A., BLINDNESS: MODERN APPROACHES TO THE UNSEEN ENVIRONMENT, p. 403.

All five of these methods can be employed for graphing, with only the fifth method being employed in a commercially made graph board. The board is covered with a fairly thick, gridded rubber matting which will accept pins. Then rubber bands can be stretched between pins for straight lines and spring steel strips can be used for curved lines. Elastic has been used in this manner sucessfully in other forms of tactilization also. At a school for the blind in Germany, the writer saw electronic circuit elements wired together with conducting elastic wires, so that they would remain taut for easy tracing of the circuit. Unfortunately, the use of elastic in graphs has its drawbacks. If a band must be stretched over a long distance, the elastic force exerted on one of the pins may dislodge it and cause it to fly across the room, thus making the whole assembly a hazard. Wexler uses a plastic tape similar to the tape used in the tape pen on paper containing raised dots representing the values of the coordinates.

Now that we have evaluated materials and methods of diagramming, some time should be given to a discussion of the relevancy of diagrams. First, there is the problem, common to both blind and sighted, of proper context. A drawing which the writer, who is blind, knew to be that of a round flask from which protruded two tubes, was interpreted by a sighted friend, unfamiliar with the context in which it was drawn, to be a lightbulb. It is obvious that proper context is important to everyone, but it is even more important to the blind. This leads directly to the two other problems confronting the blind in interpreting diagrams.

The first of these is that of visual simultaneity. The sighted student scans the diagram with his eyes and takes in many of the details immediately. If the diagram is complex, he may study it for some time in order to understand it fully, but he would still take in much more at first glance than the blind student whose view of the world is sequential rather than simultaneous. He must move his fingers over the diagram, taking it in part by part. In fact, it is known that tactile recognition of a diagram or of any shape depend upon kinesthetics, although it is not known with certainty to what extent this is important.[12] Referring again to the example of the flask diagram interpreted as a lightbulb, the friends's interpretation in this instant happend to be erroneous; however, it probably was more logical than a blind person's could have been. Had the writer not known at all what the diagram was, it is doubtful that he would have been able to interpret it without some explanation. Based on this, Wexler suggests that it is all the more important for a teacher of the elementary grades to draw the diagram part by part, showing the student each part as it is drawn with short explanations.

The other problem confronting the blind in interpreting diagrams is the inability to extrapolate from a two dimensional drawing to a three dimensional object. The sense of touch has been described as the sense which is most free of illusion and halucination. When a blind person touches a three dimensional object, if it is small enough to either hold in the hand or be felt thoroughly, he will be aware of all three dimensions in their proper orientation. He will see a table, for instance, as a flat surface with edges dropping perpendicularly. He would interpret a drawing consisting of two concentric squares with their corners

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[12] Wexler, A., Lecture to the Convention of the Association of Japanese Teachers of the Blind held in Kyoto, July, 1964.

joined by diagonal lines as just that. The sighted person <u>sees</u> the table as simply a plane surface. If he wishes to substitute a third dimension into an already two dimensional drawing of something seen in two dimensions, he can only draw a line, not perpendicular to both dimensions, but perpendicular to neither. A blind person can easily <u>learn</u> about this sort of representation, but his training in its recognition should begin early if he is to use it fully.

Because of these two barriers, in spite of the importance of diagramming, it can be seen that diagrams <u>in themselves</u> are practically useless. However, verbal explication of an extremely complex apparatus without a diagram is also nearly useless. The blind audience and the sighted explainer may visualize things quite differently. If a description the sighted person is giving does not coincide with the visualization in the mind of the blind student, he will completely lose the whole explanation. This was demonstrated clearly to the writer when another physics student tried to verbally describe a diagram representing nuclear scattering and finally ended up drawing the diagram with the tape pen. The diagram looked quite different from the visualization in the writer's mind.

If a diagram represents a simple two dimensional figure, it may be drawn and can be easily deciphered with only a knowledge of its context. A more complex two dimensional diagram, such as an involved velocity vector diagram as would be encountered in a scattering problem, can still be drawn but will require more verbal explication. A very simple three dimensional object can still be drawn with a few words of explanation. An example of this was when Mr. Wexler showed the writer a diagrammed still life of a table upon which was a vase with flowers and two chairs facing each other across the table. Only the two chairs had to be mentioned, and the writer determined in a short time the rest of the picture. For more complex three dimensional objects such as apparatus, it is best simply to demonstrate the apparatus with some explanations. However, if this is not possible, a combination of diagramming and explication should be used, with a little more emphasis on the explication. Dr. William Schiff, professor of psychology at City College in New York is now conducting research on the question of the value of diagrams to the blind.[13] There is also research on this subject at Recordings for the Blind in New York.[14] This organization which puts textbooks on discs for blind students has been inserting an experimental supplement with an accompanying questionnaire inquiring into the value of the diagrams to the reader.

B. Tactilization

There are four aspects of the tactile sense which can be taken into consideration in the tactilization of experiment output - the sense of temperature, electrical sensitivity, the sense of balance and the actual sense of touch.

An experimental demonstration of one concept of relativity and utilizing the temperature sensitivity of the skin is to fill three bowls with water. The bowl on the left is to be filled with water at about 50°C. The bowl on the right is filled with water and cracked ice and stirred

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[13] Braille Book Review, Vol. 34, July, 1964, No. 4 Braille page 87.

[14] An example of this was the textbook used by the writer "Classical Mechanics" by Herbert Goldstein which contained a supplement with some of the diagrams of the text done with raised lines.

until the temperature reaches only a few degrees. The middle bowl is filled with room temperature water. The student plunges his right hand into the ice water and his left hand into the hot water and leaves them there for awhile. Then he plunges both hands into the middle bow. The water here feels cold to the left hand and hot to the right. The instructor introduces the idea that it is cold relative to one hand and hot relative to the other. Admittedly this is not exactly the same relativity as that expressed in the theory of relativity, but it is still the writer's opinion that once one kind of relativity has been impressed upon the mind of the student, it will not at all be difficult to introduce another kind of relativity, in one way completely different, but which is still relativity. The student may be led to ask himself the question "If my judgments are not absolute, where can I find an absolute frame of reference?" Just as he must say that the same water is hot relative to one hand and cold relative to the other, a car which seems to him to be moving fast will be moving slowly relative to another car moving at a similar velocity. This kind of observation and questioning can lead to the beginning of an elementary understanding of the theory of relativity. The experiment would be done as a high school or elementary grade demonstration and can be done for sighted as well as blind students.

The only case in which electrical sensitivity is in general use involves the use of static charge generators, and this is done in classes of sighted students. Other uses of the electrical sensitivity of the skin could be found, but this would be in most cases too painful for practical use.

An experiment illustrating the conservation of angular momentum utilizes the sense of balance. A student is seated on a stool which rotates on ball bearings such as a rotating piano stool. For the duration and effectiveness of the demonstration, this can be assumed to be frictionless. The student holds two rather massive weights at arms length and enough torque is applied to his arms by the instructor or another student to give him a sizable angular velocity. When he then pulls his arms in, his moment of inertia is decreased, and the increase of angular velocity needed to conserve angular momentum will impress upon his mind this concept perhaps better than a mathematical argument. This experiment was performed in a class of sighted college students of which the writer happened to be a member. This sense may be used most effectively in experiments in mechanics, although the apparatus required to accelerate an entire student into other than circular motion would be quite grandiose and beyond the reach of most conservative teachers; other methods can be used to convey these concepts.

The sense of touch can be used in mechanics demonstrations also. Other than tactile pointer readings, the experiments would be mainly of a deomonstration nature. The motor illustrated in Figure 1 is an example. This is not the same as feeling the apparatus of an experiment about to be performed. (It is this writer's feeling that simple touching and feeling of all pieces of apparatus should never be overlooked; it is quite essential to the blind student.) The motor here embodies the concept being taught. Other experiments may demonstrate such effects as the Ampere and Oersted effects, essential for the operation of the motor, but the motor demonstrates how these effects are used in practice. The magnetic compass (Figure 2) using a magnetized hacksaw blade as a needle, is another example of this type of tactilization. These are essentially

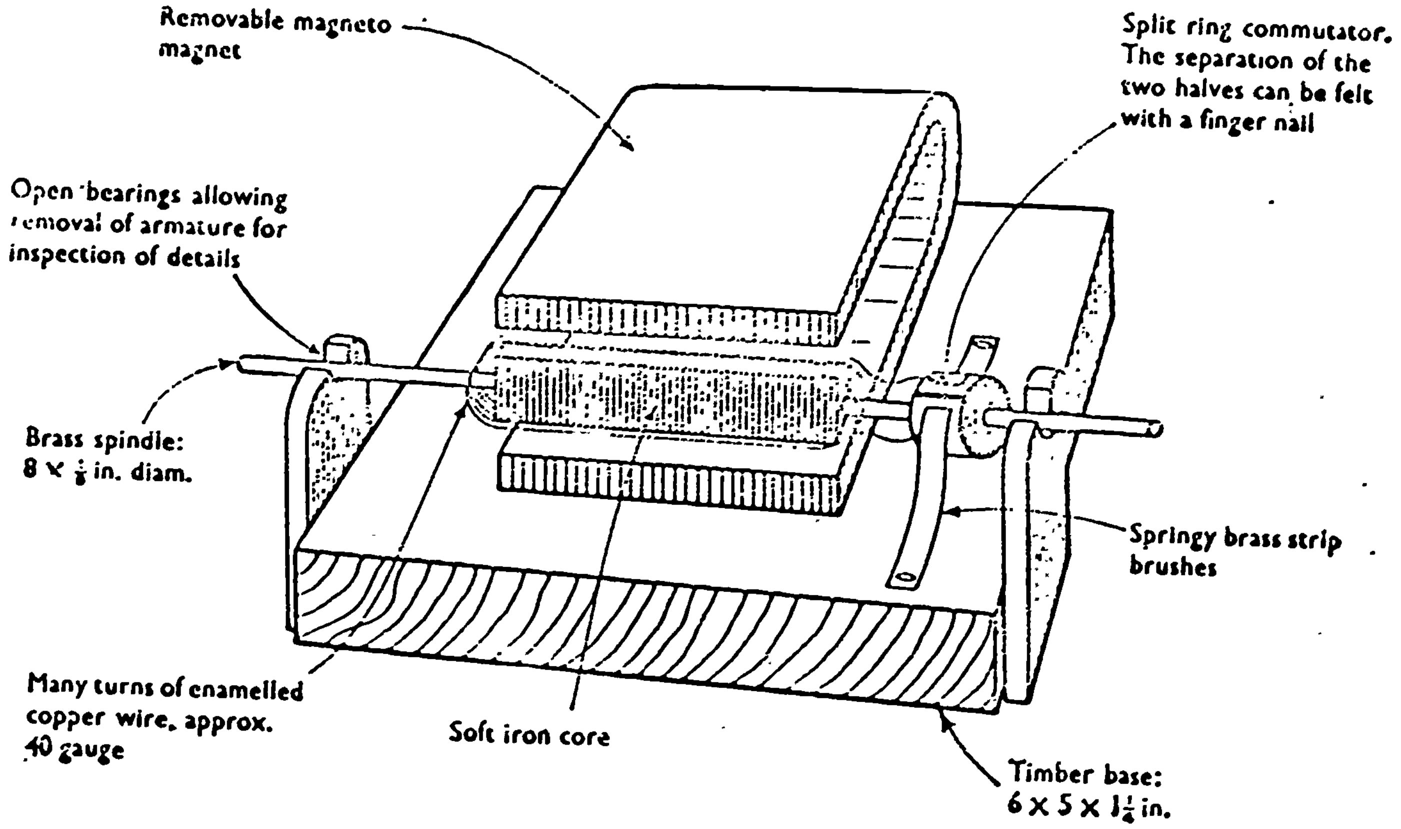

Figure 1. Demonstration Dismountable Motor (from Wexler, ref. 15).

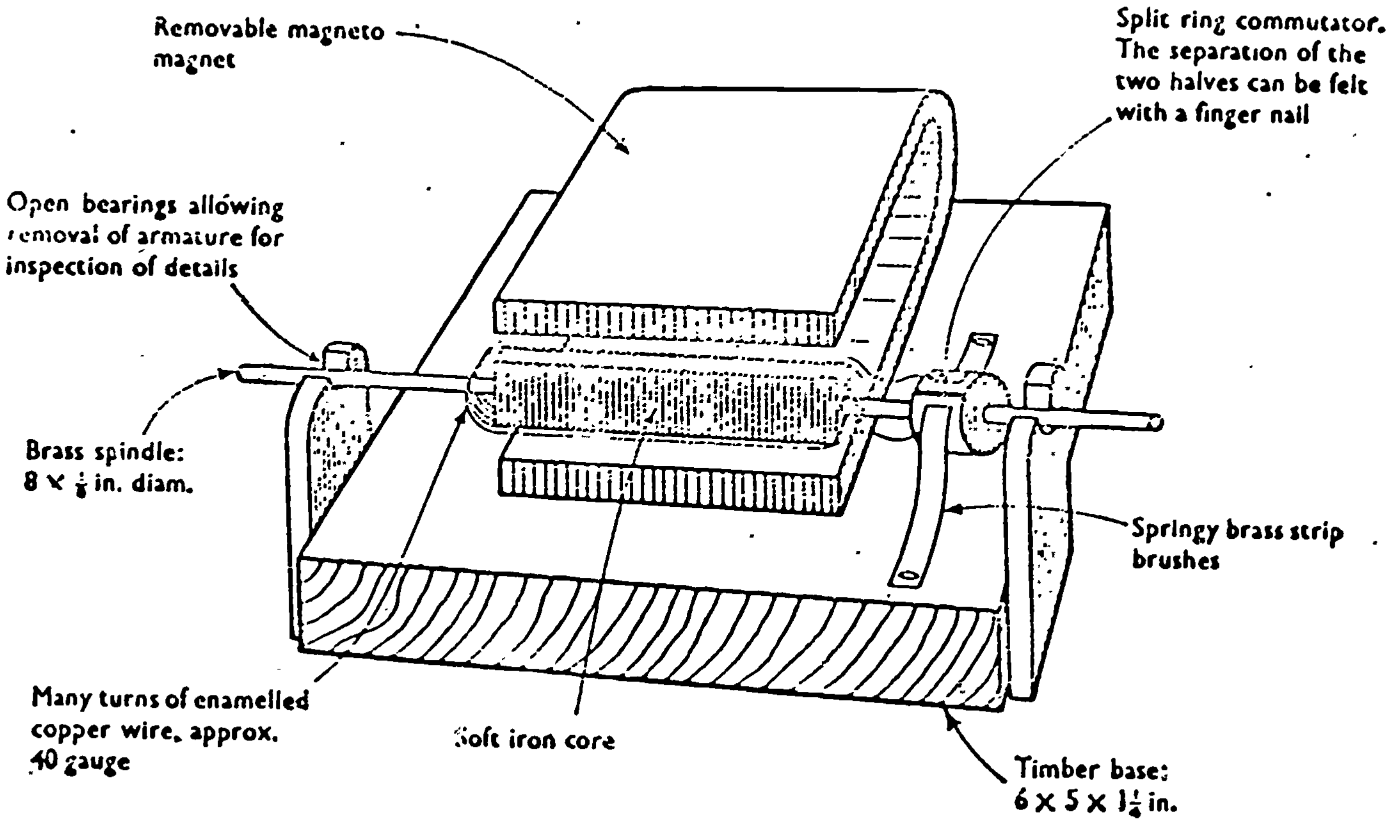

Figure 1. Demonstration Dismountable Motor (from Wexler, ref. 15).

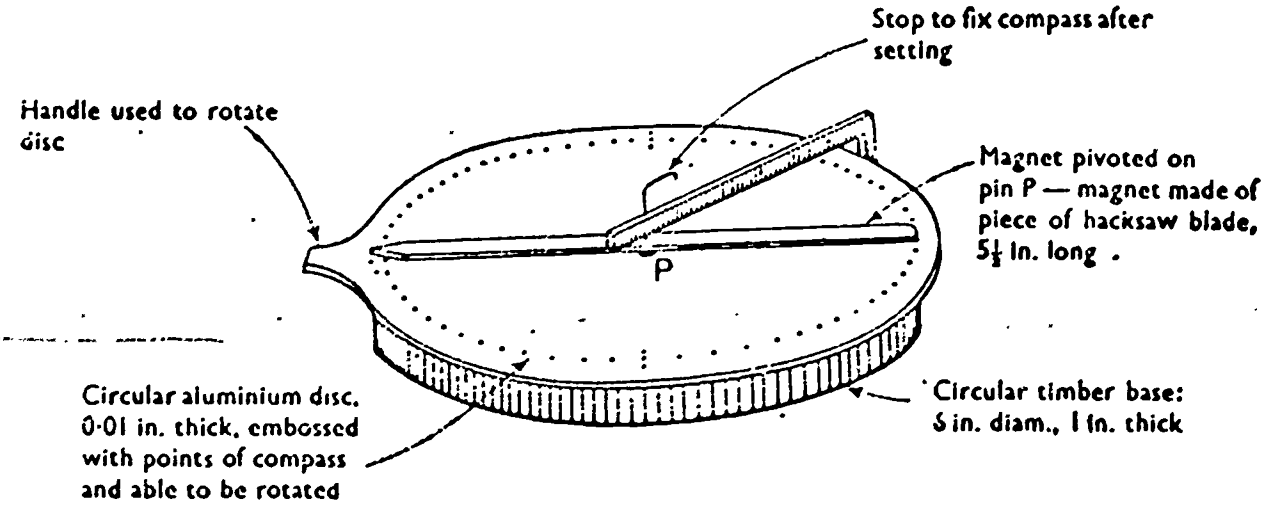

Figure 2. Magnetic Compass (from Wexler, ref. 15).

models of the devices represented - the compass somewhat more so than the motor. The motor, though extremely inefficient, is at least of normal size.

A slightly less tangible concept than that of the motor is illustrated in Figures 3 and 4. The device is essentially a dry cell in reverse, with the electrolyte a liquid rather than a paste. If the hydrogen oxygen mixture were ignited at the top of the pipe, the student would know that the electrolysis of water did something which could be burned, but the balloon which can be felt shows the student that it is some kind of gas. Another example of the use of the sense of touch is a demonstration of wave propagation. A cork is set floating near the edge of a bowl of water. A disturbance is then set up in the middle of the bowl or at the opposite edge, and the student's finger is placed on the cork and he can feel its bobbing when the wave reaches it.

C. Magnification

Thus far, experiments utilizing the sense of touch have been of a strictly demonstration nature, and have not involved quantitative measurements. The easiest and by far the best way to make quantitative measurements is by tactile reading. Even the reading of the electronic devices discussed in Section II will be a tactile pointer reading. The most obvious way to go about this would be to remove the face from a conventional meter and either notch the edges around the dial to indicate various points on the dial or to place a braille dial over the printed one. A drawback to this method is that quite often the mechanism of the meter is so delicate that touching the needle could ruin the meter. One method of getting

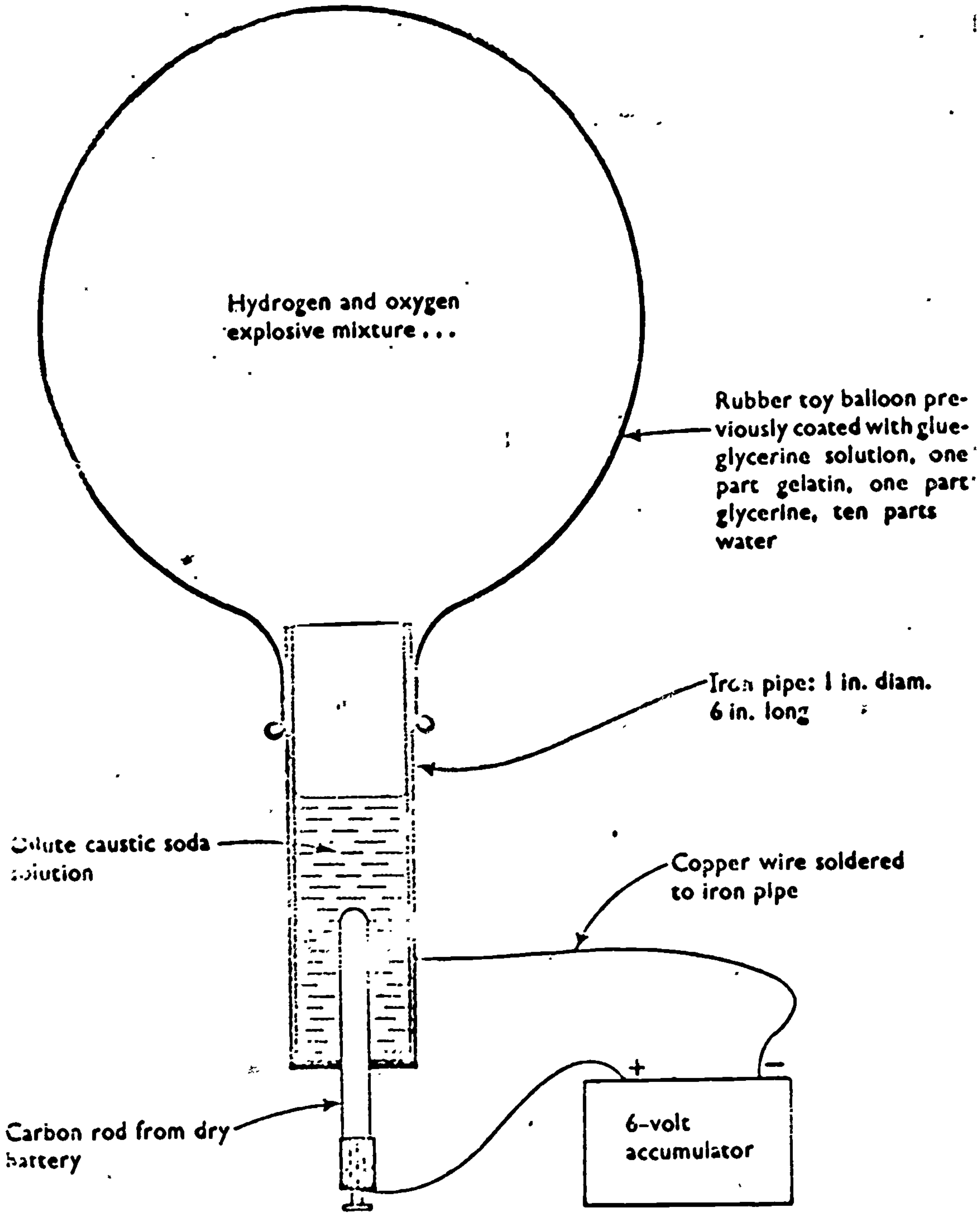

Figure 3. Demonstration of Electrolysis of Water Forming Explosive Mixture (from Wexler, ref. 15).

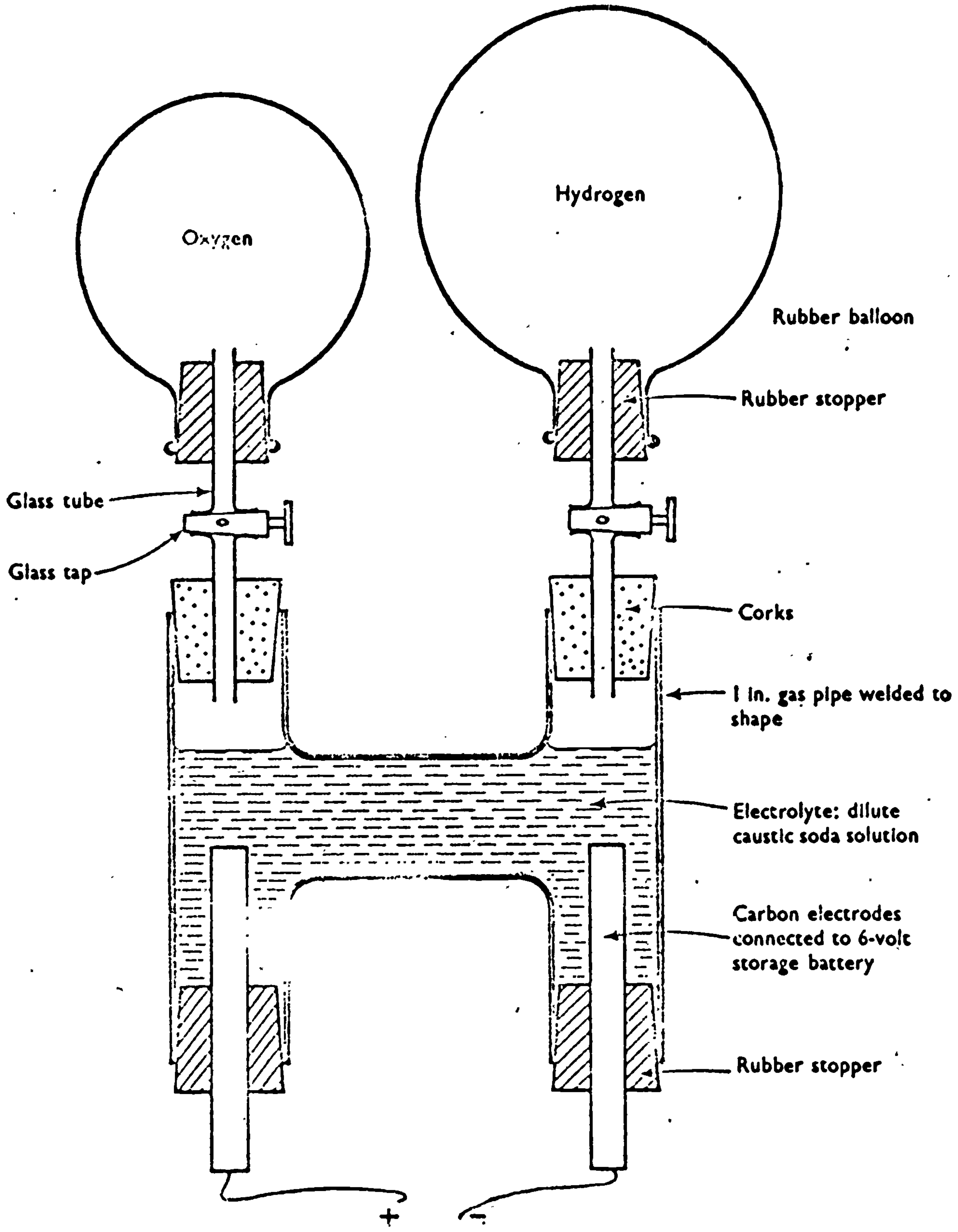

Figure 4. Electrolysis of Water (from Wexler, ref. 15).

around this problem is to clamp the needle in place after a reading is taken. A braille label is useful as long as the braille is embossed on a transparent material. Otherwise the instrument will be made useless to sighted students or workers who may be using the same instrument. This type of reading also results in a loss of precision. The eye can locate a point to within a distance of 0.625 mm.[15] The finger requires a space four times that great. Therefore to obtain an amount of precision equal to that of the equivalent reading made by a sighted reader, the brailled scale must be magnified four times. Most instruments with magnified dials are designed for the use of blind students only, or at least mainly for that use, although if blind and sighted students happen to be working together, the instrument could be provided with a printed scale also.

A micrometer developed by Wexler (Figure 5) contains a cylinder on the end of the screw portion of the instrument and a thin piece of metal standing upright which serves as both a pointer with which to read the marking around the edge of the cylinder and as a sliding index for gross measurements. The model used by Wexler is actually a commercial micrometer caliper with a screw pitch of ten turns per inch. There is a notch in the cylinder at the zero mark, into which the pointer clicks upon every rotation of the cylinder. Each of these clicks represents 0.1 inch. These tenths can also be read as markings on the sliding index. The circumference of the cylinder is then marked off into a hundred divisions. Therefore, an accuracy up to 0.001 inch can be had. The magnification evidences itself in the cylinder which is about 1.5 to 2 inches in diameter.

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[15] Wexler, A., EXPERIMENTAL SCIENCE FOR THE BLIND, p. 16.

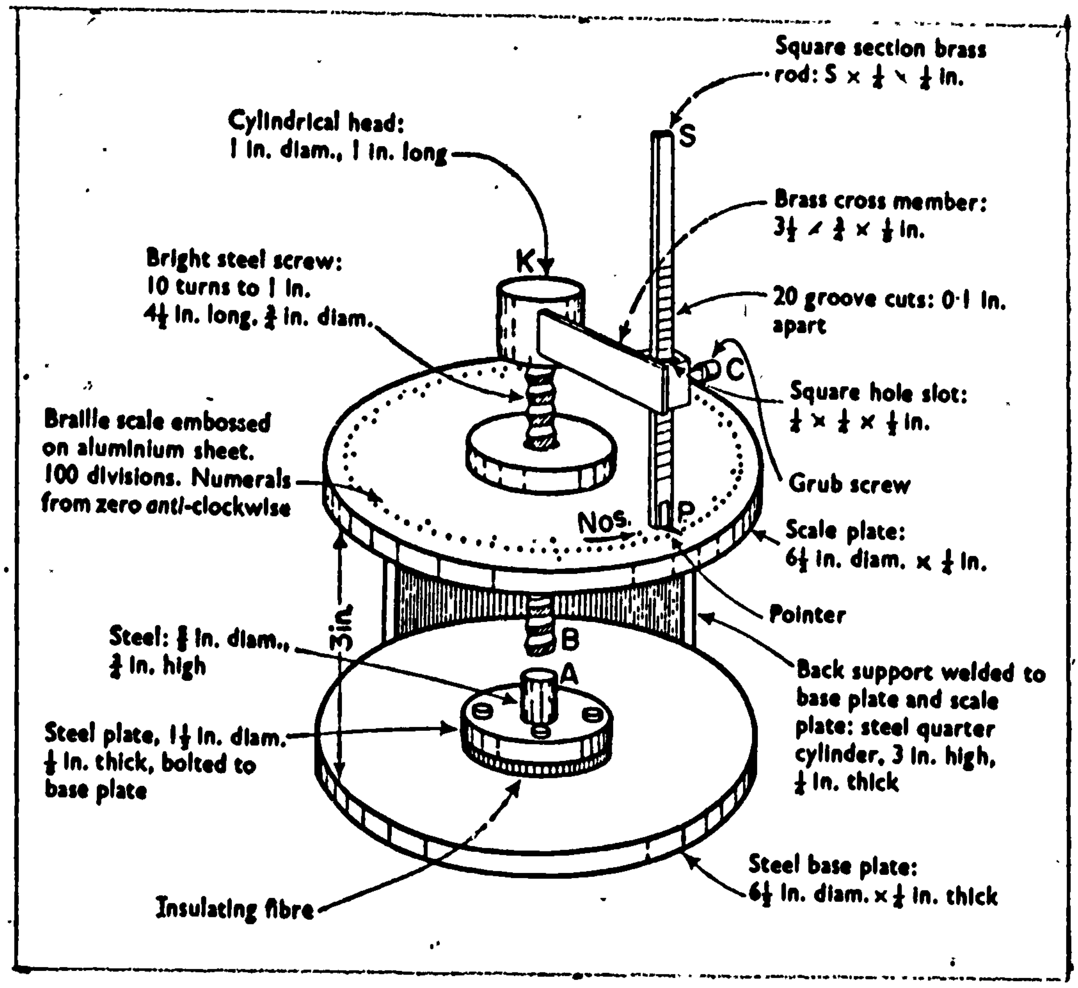

Figure 5. Micrometer Screw Gauge with Braille Scale. Range: 2 in. in 0.001 in. (from Wexler, ref. 15).

The spring balance in Figure 6 is another example of magnification. It can measure to within one part in one hundred. This means that various weight magnitudes can be measured simply by using springs of various spring constants. Wexler, with three different springs, weighs 100 grams to within 1 gram, 10 grams to within 0.1 gram, or 1 gram to within 0.01 gram.

The tactual meter reader of Figure 7 [16] is the epitome of magnification. Even the voltages to be measured are amplified. The difference between the amplified voltage and a standard voltage across the potentiometer turns the servomotor which adjusts the potentiometer until the difference is zero. This also moves the pointer over the magnified scale. The diodes allow for both positive and negative voltages to be measured. This might be considered the "brute force" method of measurement. It can be used in conjunction with a visual meter. It should draw no more current than an ordinary vacuum tube voltmeter, and its use would be convenient in industrial applications, where ambient noise would make the use of auditory equipment difficult.

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[16] Proceedings of the International Congress on Technology and Blindness, American Foundation for the Blind, New York, Vol. 3, 1962.

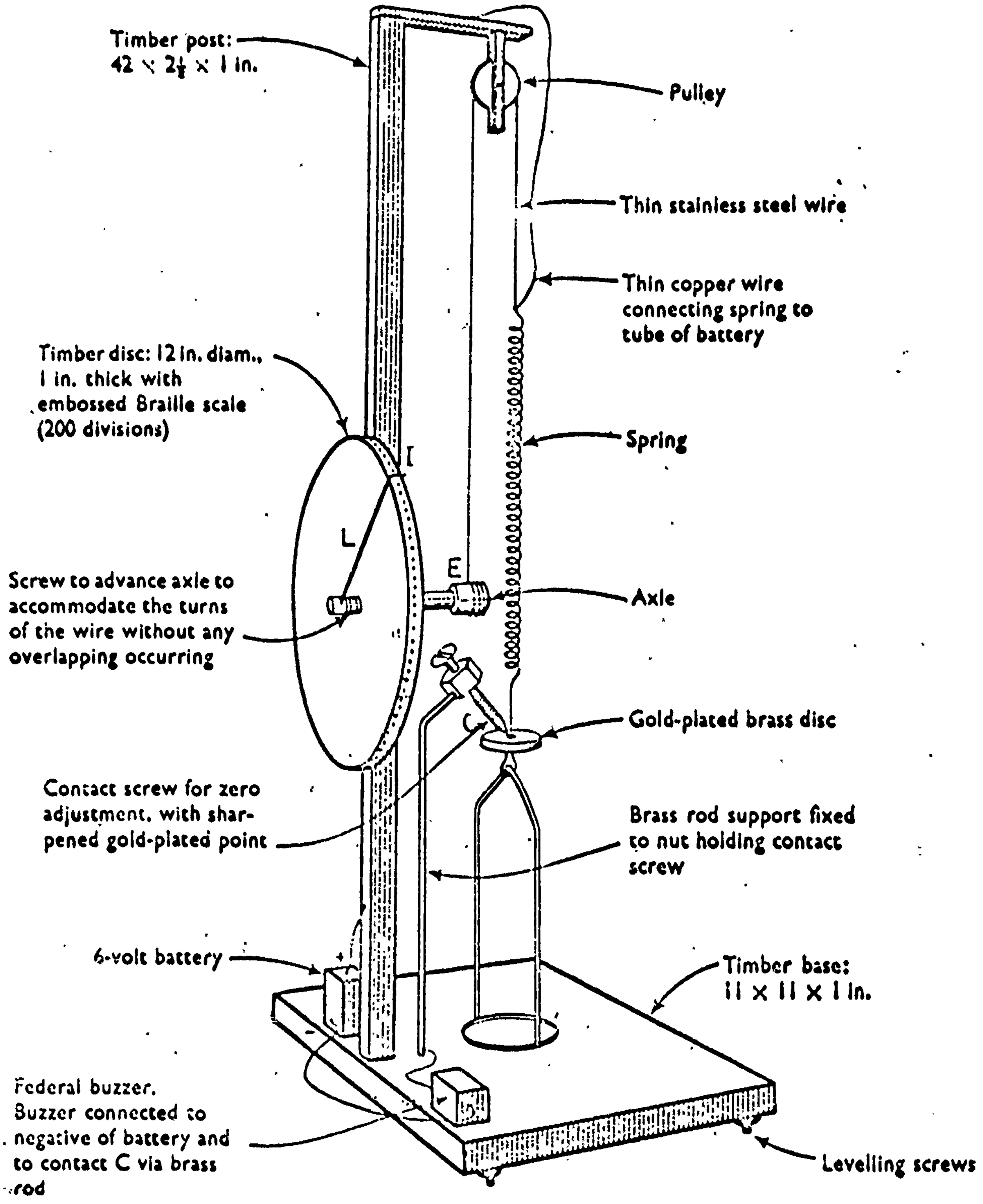
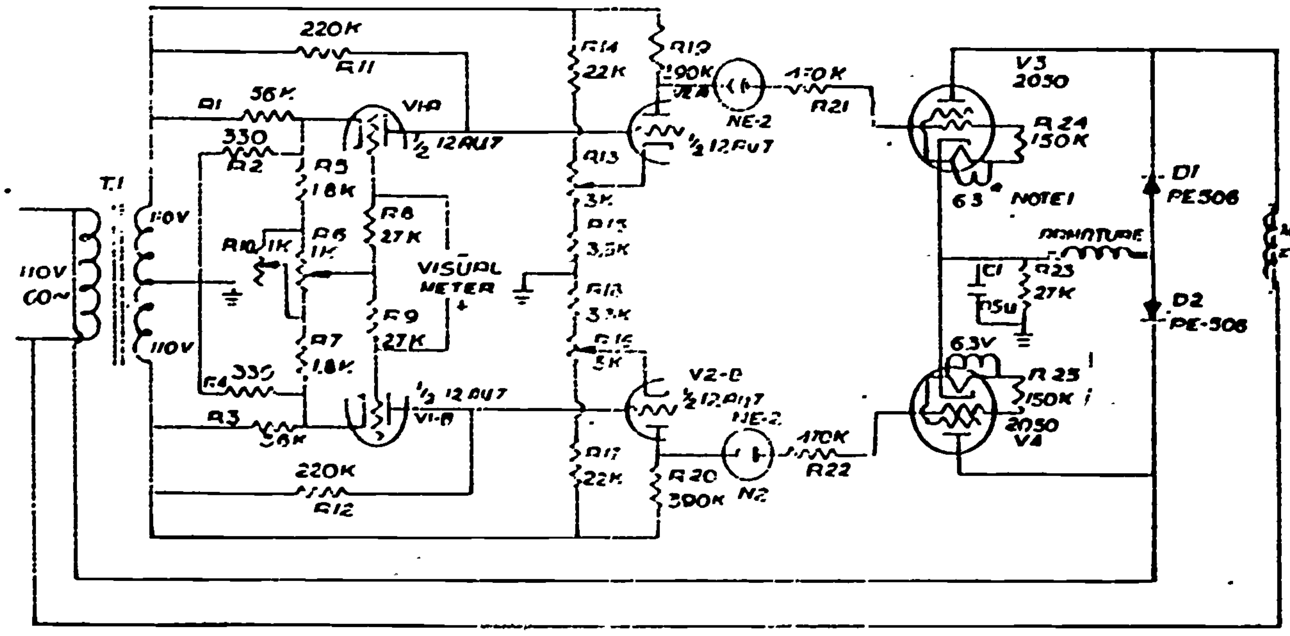


Figure 6. Spring Balance (from Wexler, ref. 15).



NOTE 1
PHASE OF V3 AND V4 FILAMENT
TRANSFORMERS MUST BE CORRECT
TO PREVENT CONTINOUS FIRING
OF V3 AND/OR V4

Figure 7. Tactual Meter Reader-Circuit Diagram (from Proceedings of the International Congress on Technology and Blindness, ref. 16).

III. AUDIFICATION

Audification, a term coined by Wexler, is the method of laboratory work adaptation for the blind whereby experiment readout or output is manifested partially or entirely in terms of auditory signals. It is by far the most widely used method of adaptation.

Early examples of audification on the demonstration level were very ingenious. A demonstration of the time dependence of the flow of heat by conductivity consists in attaching several marbles with wax along the length of a copper rod.[17] When the temperature of the rod rises at a spot where a marble is attached, the wax will melt and the marble will drop to the table. In this way, the blind student can "hear" the heat flow along the rod. If the distance between marbles is measured, (done easily with a brailled ruler or meter stick) and the time between marbles' falling off measured (with a "stop watch" which will be described subsequently) this demonstration could be turned into a quantitative experiment, and the equations of heat flow could be at least introduced, if not solved, at the high school level.

A very similar demonstration illustrating the absorption of heat by black objects consists of attaching a marble with wax to each of two objects - one black and the other reflective - and heating both simultaneously to determine which marble falls off first.[18]

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[17] Evans, Edward, "Notes on Elementary Science", THE TEACHER OF THE BLIND, Vol. 16, No. 2, Nov. 1927, p. 38.

[18] Ibid., p. 39.

The description of the demonstration went no further than this; however, in the opinion of the writer, the experiment could be dramatically improved and would take on the added level of demonstrating still further the similarities between heat and light, if beakers of differing size, thus giving a different tone, were placed under each marble. Then the blind student could test each object with a light probe (discussed later) to determine which was black and which reflective, tapping the respective beaker as he did so, determining the pitch associated with the black and with the reflective object. Heat would be applied to both objects, and since each marble would give its own distinctive "call" when it fell, there would be no doubt as to which one falls first.

Another early experiment in audification, illustrating expansion of gases when heated, consisted of heating a flask of air which was allowed to bubble into another flask of water.[19] The sound of the bubbles can be heard, and the student learns that the gas moves from one container to the other through expansion.

Still another ingenious use of pure audification is Wexler's Ampere and Oersted Effect apparatus shown in Figures 8 and 9.

A method of taking quantitative measurements using pure audification uses a stop watch developed by Wexler and improved upon by the writer. It is nothing more than a magnetic tape recording of someone reading a stop watch second by second. A bell or buzzer sounds at the beginning of the tape to indicate when the timing begins. The blind experimenter runs the tape at zero volume level during the period of the run and switches

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[19] Ibid., p. 37.

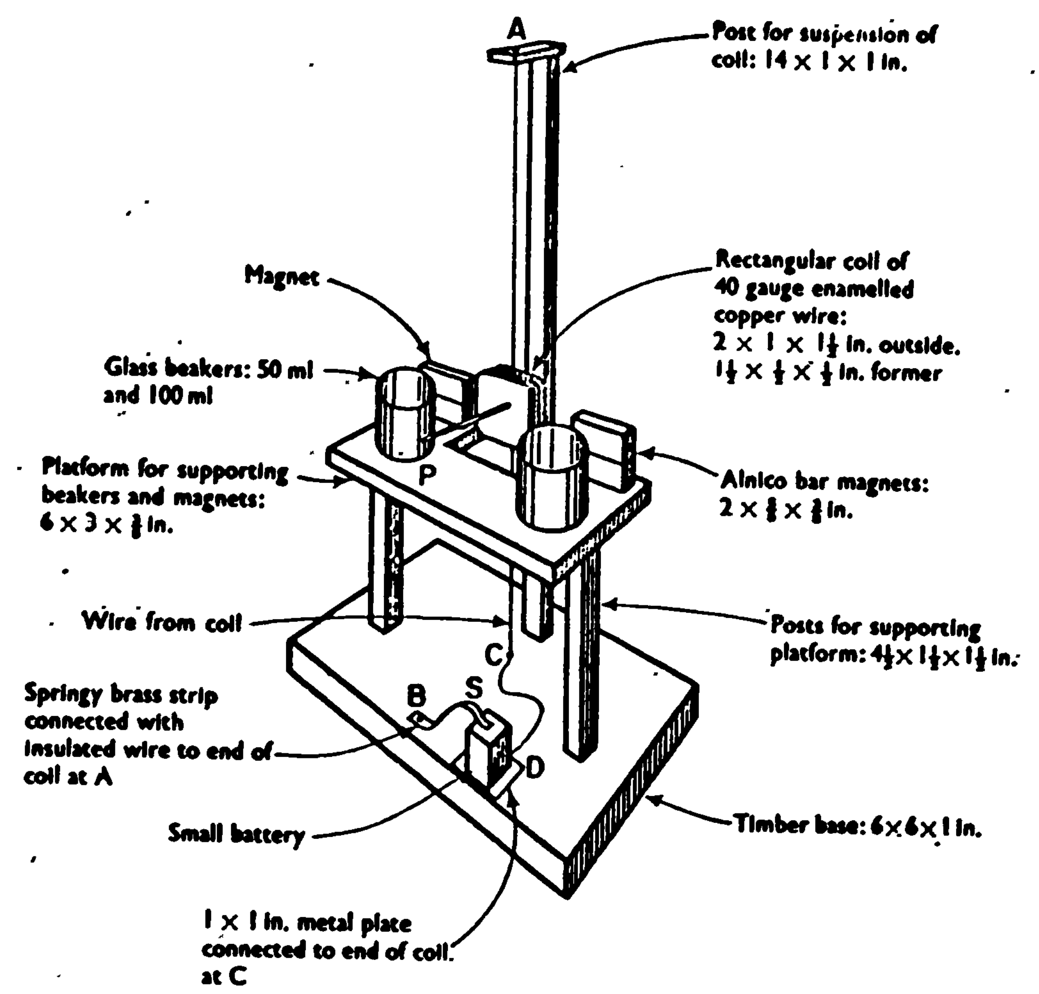

Figure 8. Apparatus for Demonstrating Ampere Effect (from Wexler, ref. 15).

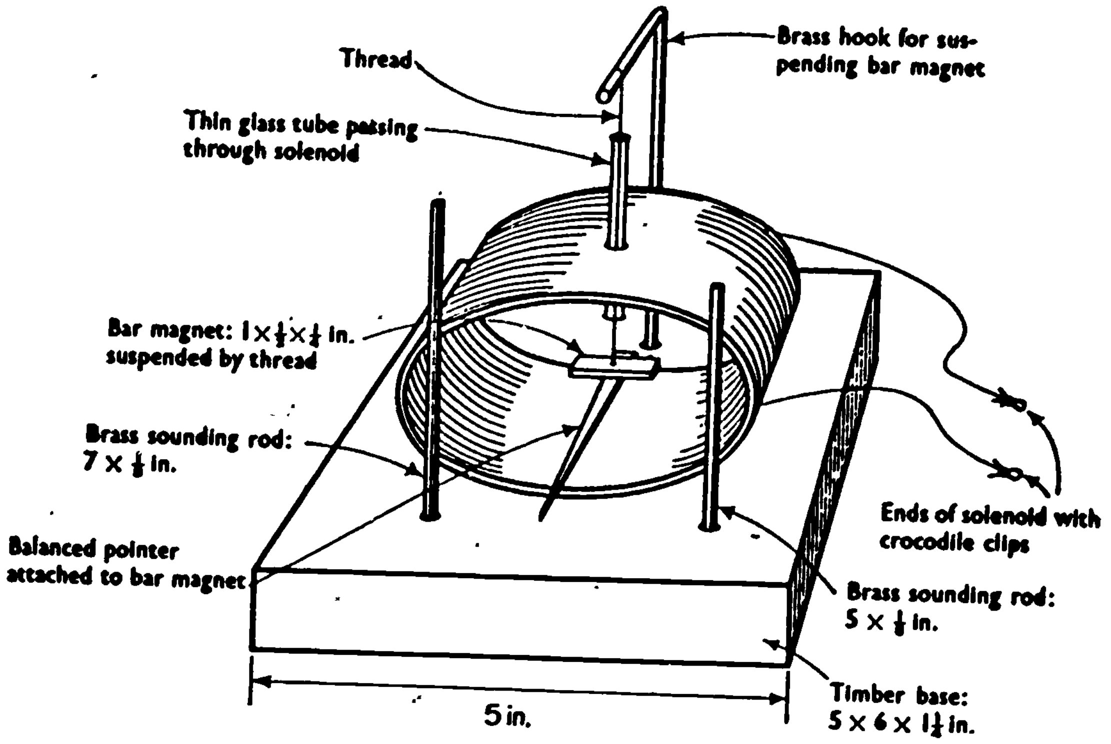

Figure 9. Apparatus for Demonstrating Oersted Effect (from Wexler, ref. 15).

off the tape when the run has been completed. When he turns up the volume and turns on the tape again, the next number called will indicate the length of the run - or one less than the number called. This method is accurate to within the second. An improvement allowing for more accuracy is to count two second intervals starting with "0-one" meaning zero minute and one second, 0-two, etc. Along with this would be recorded a series of clicks at a constant rate of five or six per second. During the running of the experiment, the tape would be played at twice the recorded speed. Thus the two second intervals counted at recorded speed would appear as one second intervals interspersed with clicks at a frequency of ten per second. After the run, the speed is returned to the recording speed and the tape is switched on. The number of clicks before the next number are counted. If m is the number of clicks counted from the end of the run, (each click representing a tenth of a second) and n the number announced, the time taken by the run will be (n-1) and (10-m) tenths seconds. The accuracy of this "stop watch" will then be to within 0.1 seconds, adequate for most high school experiments. Further accuracy can be had by further speedings of the tape; however, this may require more than one tape recorder or a more expensive model with more than two speeds, and this is not really necessary since other methods involving automated time measurements for advanced experiments are available.

For the present method, the only equipment necessary is a two-speed tape recorder and either a metronome which can produce up to six clicks per second, or an audio oscillator capable of frequencies as low as six cycles. This would of course have to be a square wave output so that the oscillations could be detected as clicks in the loudspeaker of the tape recorder, and could be one more of the many uses of the blocking oscillator mentioned in Section III. In fact, a reader of a stop watch may not even be necessary. If the blind student possesses a short wave radio, he can find one of several stations giving the time, which produce a beep or click every second. He would then only have to count the interval between two beeps or clicks. He could do this listening to the radio through earphones, or he could add the radio signal to the clicks and voice counts. At twice normal speed, the beeps or clicks from the radio would mark the half second; however, it could become unwieldy keeping track of clicks, beeps and numbers.

In a serious experiment, none of these principles is often used in its pure state. In most cases, audification and magnification are used in conjunction with each other, and in some cases, all three are employed. Such a case is the "microtact". This is not tactilization in the pure sense, since the "finger" is a tiny wire, but it is tactilization in a real sense. A meter needle, for example, is felt by the wire, and the circuitry of an electric bell or buzzer using the meter needle and feeler wire to close the circuit might be thought of as a simple "nervous system". The wire is attached to an external pointer with a magnified brailled scale.

Microtactilization is also an efficient way to measure the level of liquids in a narrow tube. A probe in the form of two small wires connected as a switch in a bell or buzzer circuit protrudes into the tube. This can be part of a bent wire arrangement as in Figure 10, with the external part of the wire equipped with a pointer running along a graduate braille scale. The conductivity of the liquid closes the circuit and the sound of the bell indicates that the probe is at liquid level. If the

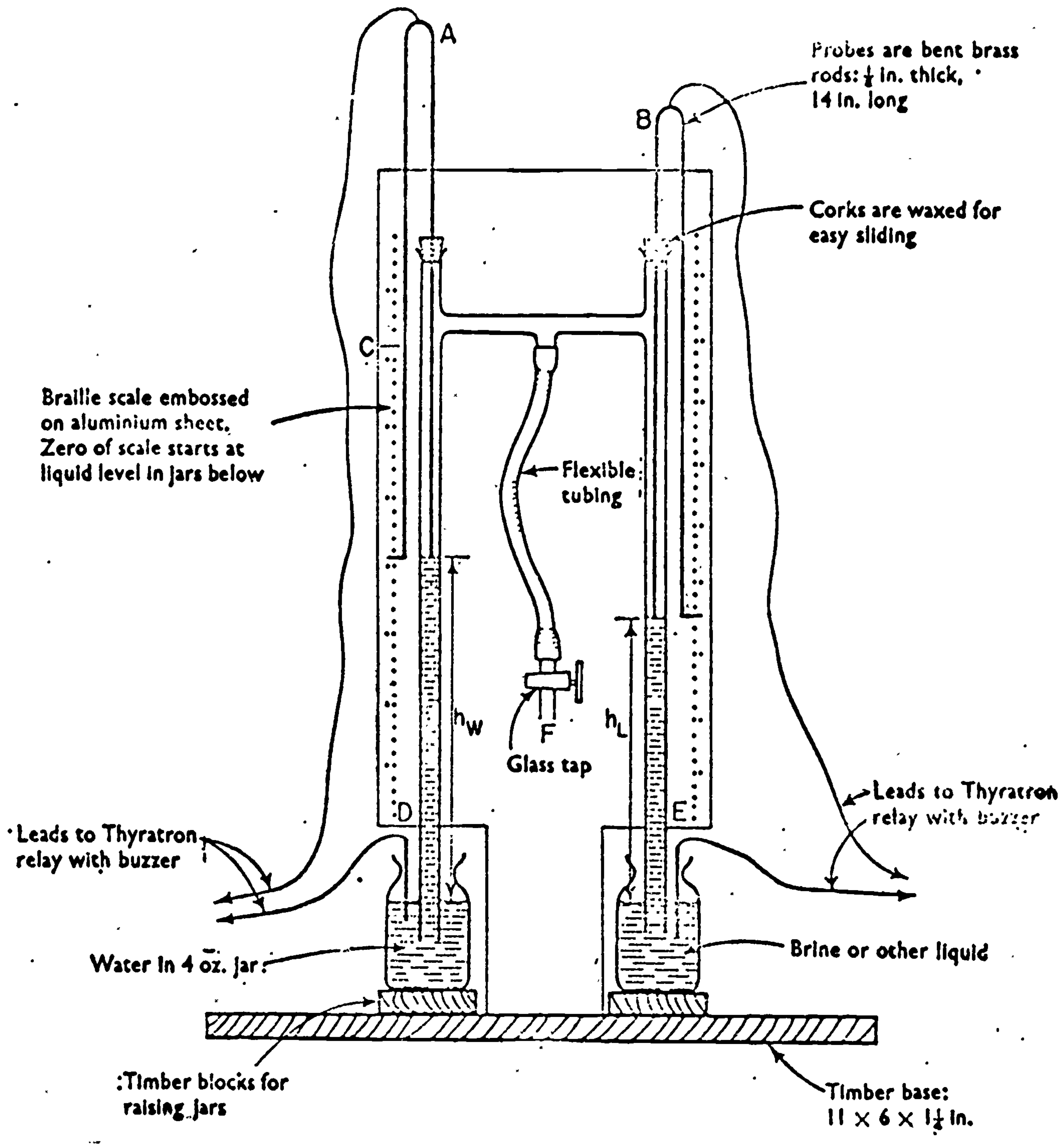

Figure 10. Apparatus with Probes for Measuring Liquid Levels (from Wexler, ref. 15).

conductivity is extremely low, as is the case when using pure water or non-ionic solutions the thyratron-relay circuit of Figure 11 can be employed.

Experiments involving electrical measurements are particularly amenable to audification. Much of the sound producing apparatus used in physics experiments outside the direct study of sound itself is electrical, so why not use it for electrical measurements? One of the earliest examples of this use of audification is the adaptation of the simple wheatstone bridge or voltage-measuring potentiometer circuit. The voltages involved in these measurements are "chopped" by a mechanical vibrator, and an earphone is substituted for the galvanometer. A variation of this is familiar to even sighted users of impedence bridges. The voltage is supplied by an oscillator. Since reactances need alternating voltages, the impedence bridge is a "natural" for blind laboratory workers. This method can be applied in as simple a manner as modifying a wheatstone bridge for use in a high school experiment or in as complex a manner as the auditory circuit analyzer of Figure 12.[20]

A pocket sized potentiometer voltmeter operating on this same principle has been developed in Germany.[21] And Robert Gunderson, an American blind radio amateur, has done much for other radio amateurs using the null principle. (See Figure 13.)[22] The meter is set to full scale,

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[20] Witcher, C. M., "Circuit Analyzers for the Blind", ELECTRONICS, Vol. 20, 1947.

[21] Proceedings of the International Congress on Technology and Blindness, American Foundation for the Blind, New York, Vol. 3, 1962.

[22] Gunderson, Robert, "Reading Voltages by the Comparison Method", BRAILLE TECHNICAL PRESS, Dec. 1958, p. 36.

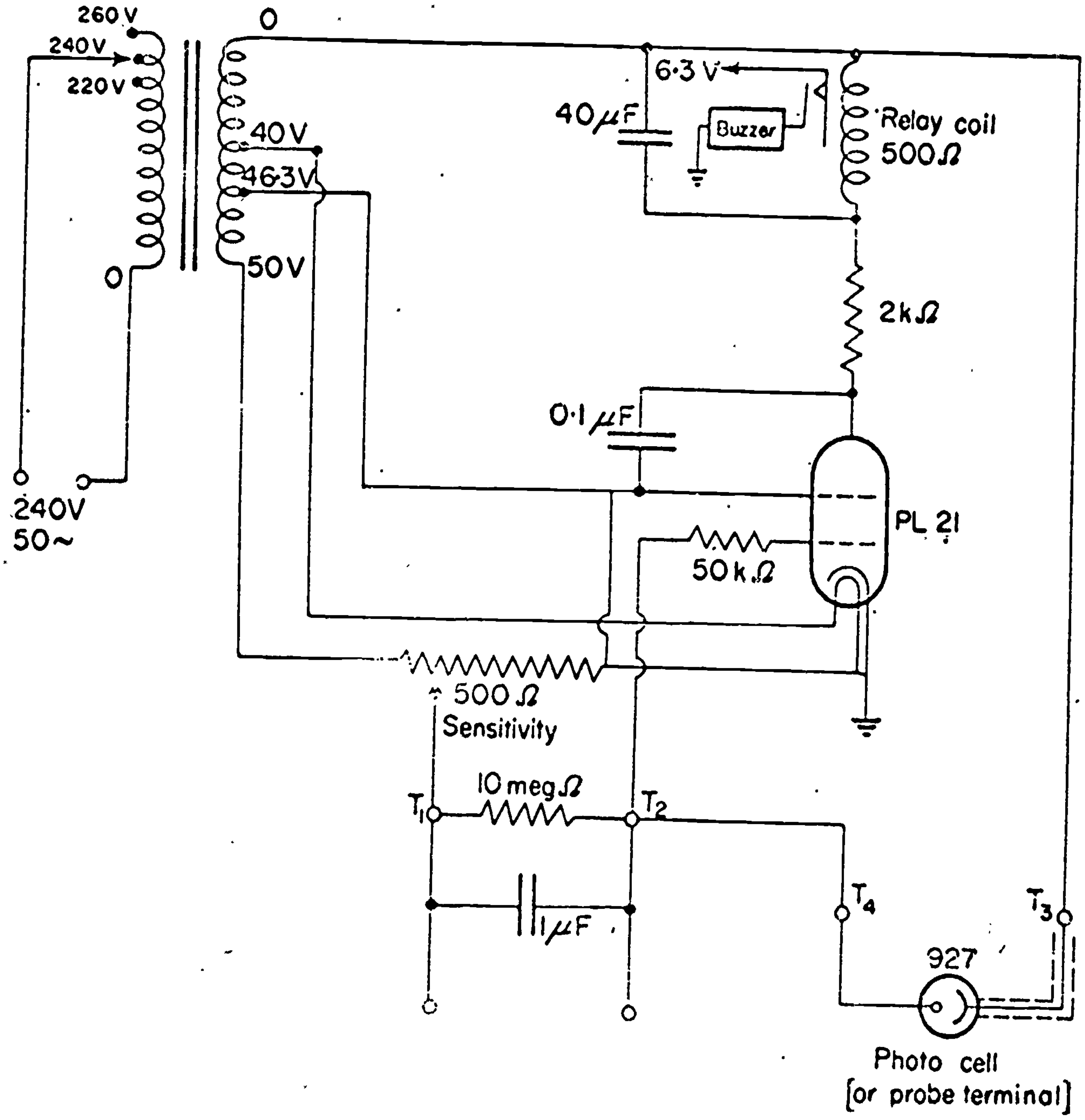

Figure 11. Thyratron Relay (from Wexler, ref. 15).

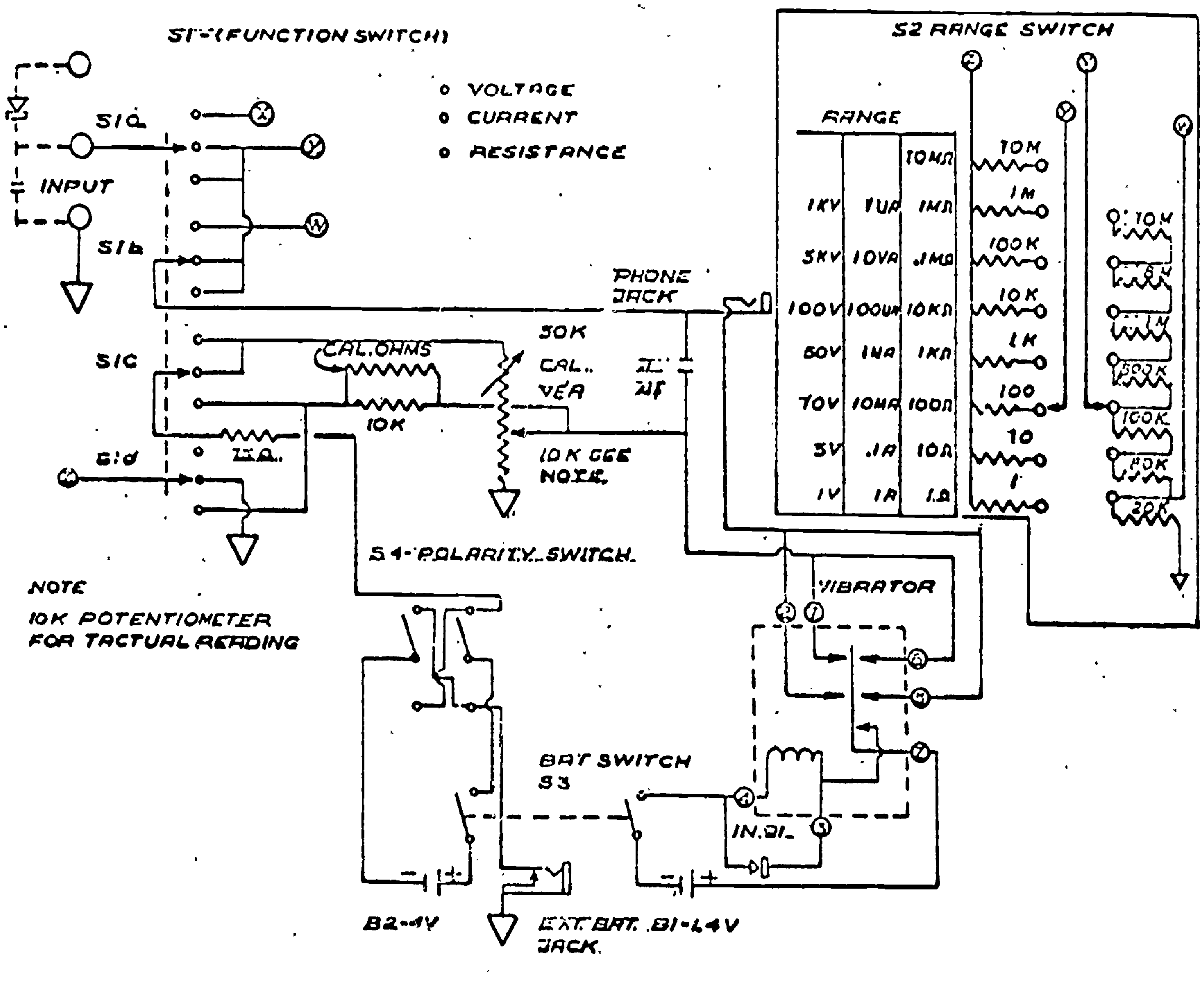

Figure 12. Auditory Circuit Analyzer (from Witcher, ref. 20).

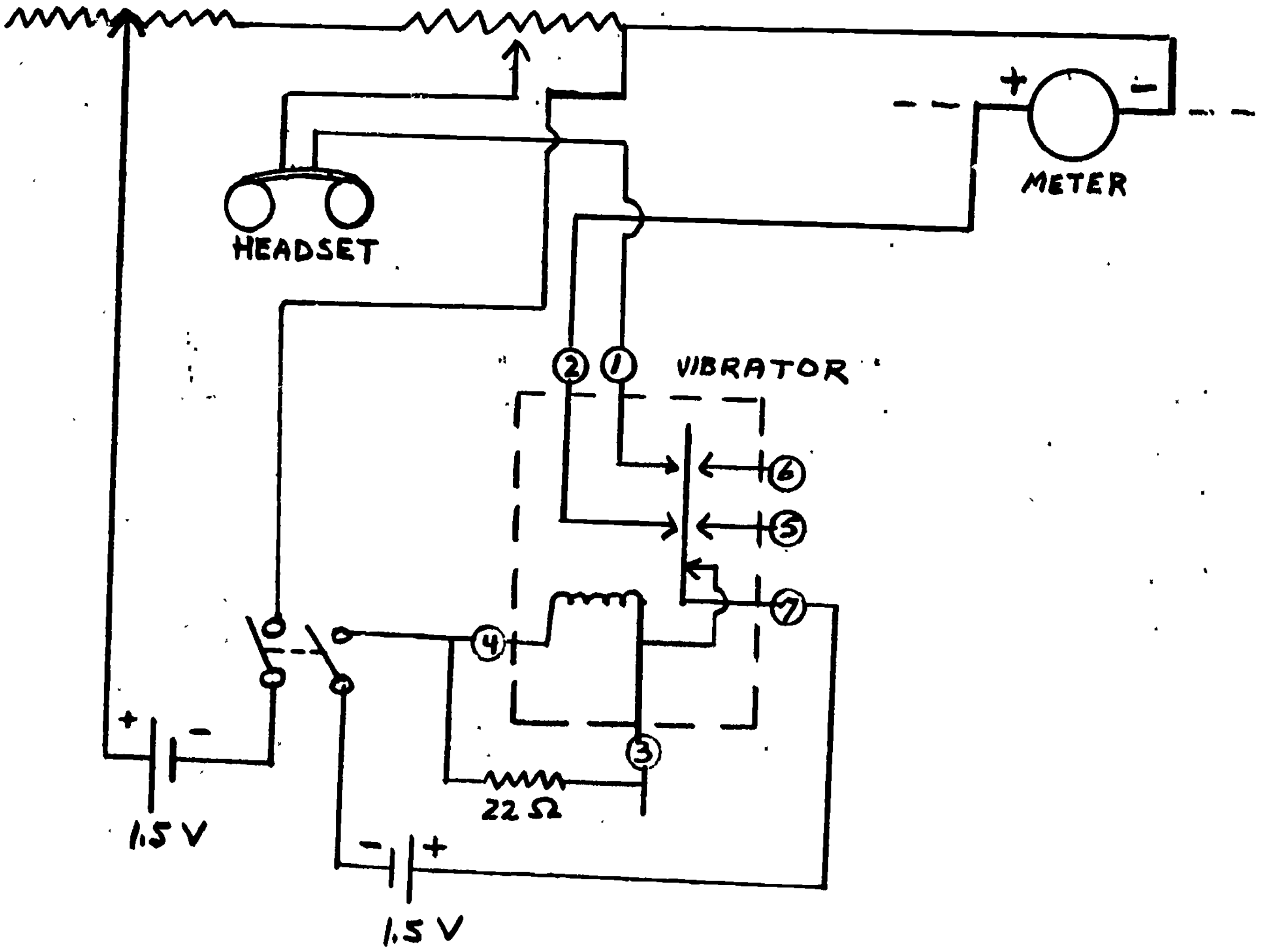

Figure 13. Auditory Meter Reader (from Gunderson, ref. 22).

and the calibrating rheostat is used for null in the headset, with the potentiometer set at full scale. A comparison is made of the voltage in the meter circuit and that of the potentiometer, and when they are equal, a null appears in the headset. This resembles in principle the servo-operated tactual meter movement described above. Essentially, the servo motor takes the place of the operator's ears and hand.

A capacitance bridge developed by Gunderson uses a mechanical vibrator rather than an oscillator for its A.C. source. (See Figure 14.)[23] Another type of null capacitance bridge uses a relaxation oscillator as the A.C. source.[24]

The two variables to be considered in any adaptation involving audification are the intensity and frequency of the sound. The devices just mentioned employ intensity changes for making measurements. The null method is the only one where intensity variation can be used with any accuracy, because the logarithmic intensity response of the ear makes it much less sensitive to intensity than to frequency variations. Therefore, many circuits have been designed for measuring instruments involving frequency changes. This can take the form of finding peaks or dips in pitch of the output, thus locating maxima and minima, or a constant change in pitch which is a function of the variable being measured. Since this latter arrangement alone would be useless to those without a good musical ear, it is used in conjunction with a calibrated tone source.

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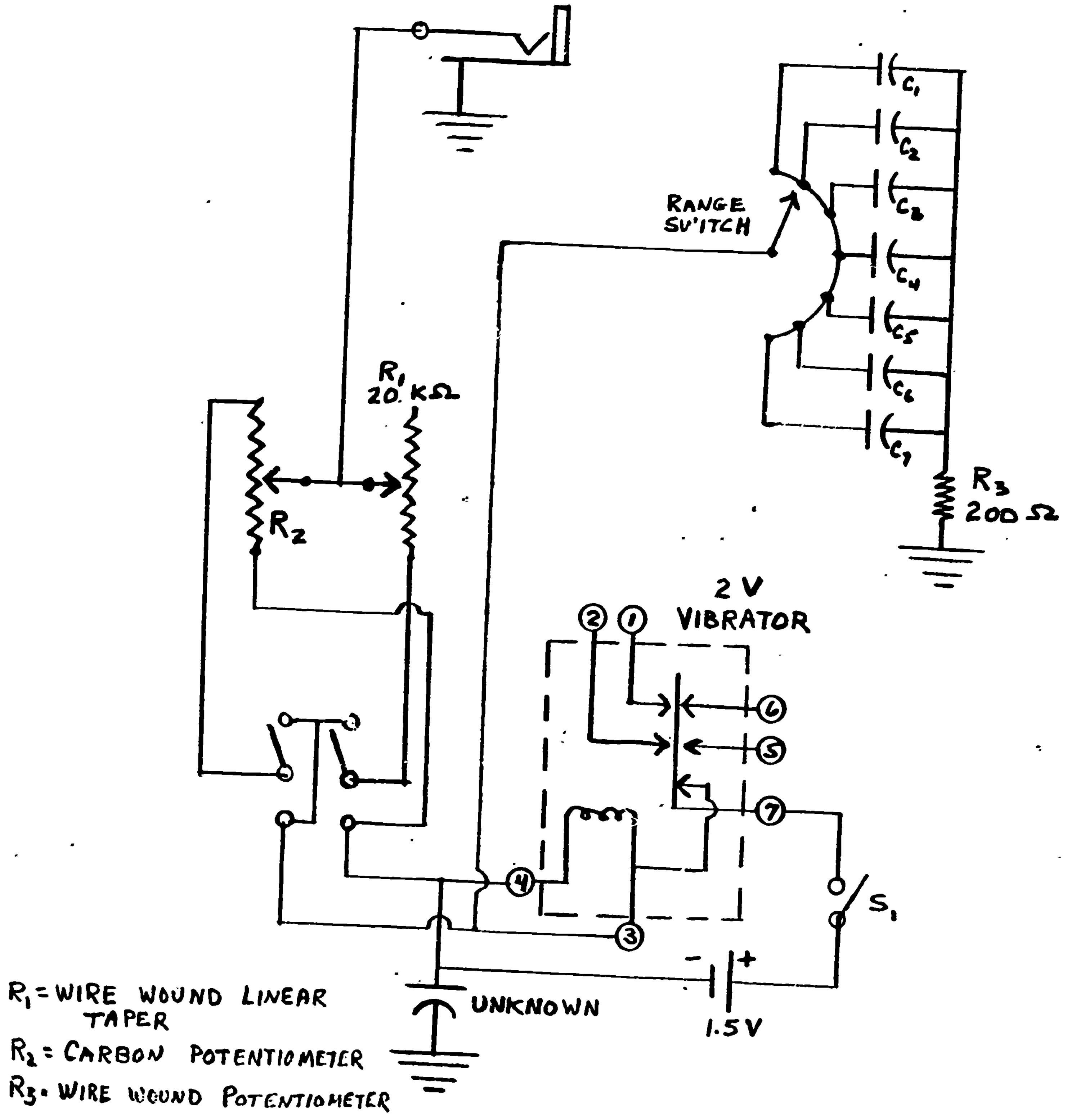
[23] Gunderson, Robert, "A Simple Capacitance Bridge", Ibid., Nov. 1951, pp. 30-34.

[24] Evans, Quentin, "A Simple Capacitance Bridge", Ibid., Nov. 1958, pp. 43-53.



R_1 = WIRE WOUND LINEAR TAPER
R_2 = CARBON POTENTIOMETER
R_3 = WIRE WOUND POTENTIOMETER

Figure 14. Simple Capacitance Bridge (from Gunderson, ref. 23).

When the source tones are made equal to one another, the reading is taken on a magnified braille scale.

One milliameter design, for example, used one winding of a reactor as the inductance of an audio oscillator.[25] The current being measured is fed to another winding of the reactor. The change in inductance with the change in current thus causes a change in pitch. If a calibrated variable inductance is then arranged through a switch setup whereby it can be quickly cut into the circuit replacing the variable inductance, a pitch comparison can be made and the reading taken on a braille scale calibrated in units of current.

A. The Light Probe and Uses of the Resistance Controlled Oscillator

One of the most fantastically versatile instruments is one so simple that it could easily be overlooked. This is simply a neon bulb relaxation oscillator or transistor blocking oscillator such as that shown in Figure 15. The voltage across a capacitor being discharged through a resistor can be given by the expression:

$$e = E \exp(-t/RC)$$

where e is the instantaneous voltage at any time, t, E is the inital voltage, R is the resistance and C the capacitance. The frequency of firings of a neon lamp in a relaxation oscillator circuit or oscillations of a blocking oscillator will then be inversely proportional to the time

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[25] Brier, H. S., "Oscar, a Milliameter for the Sightless Amateurs", C.Q., July, 1948, p. 22.

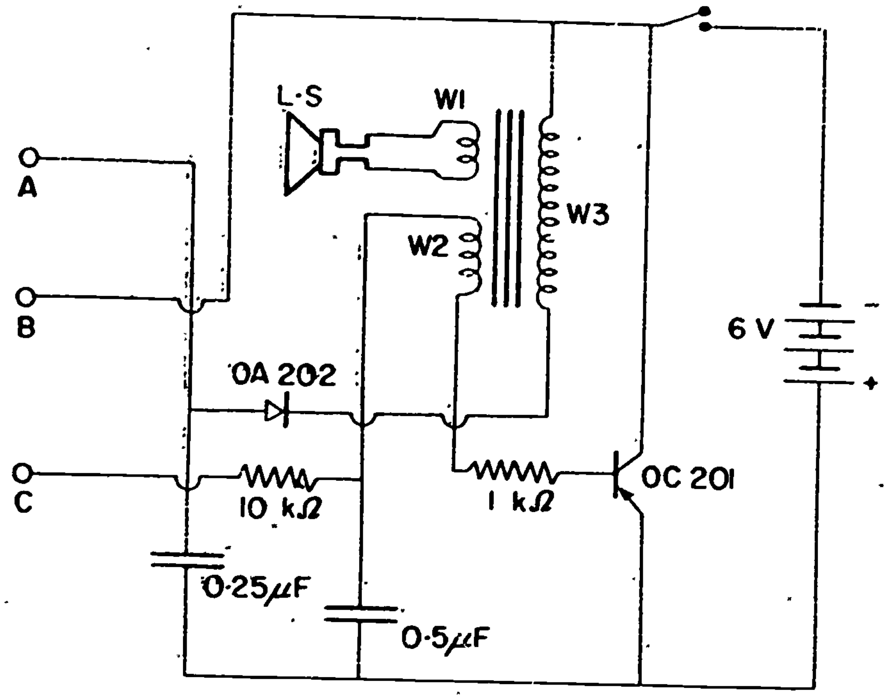

Figure 15. Audible Light Intensity Indicator (from Wexler, ref. 15).

constant RC, or in other words, inversely proportional to the resistance, R. We immediately see a method for measuring resistances. The tone associated with an unknown resistor connected to terminals brought to the outside of the apparatus can be compared with that of a calibrated linear potentiometer or with a resistance decade whose value can be read on a brailled scale. With a continuity meter employing a relaxation oscillator, the continuity resistances as high as 10^8 ohms can be checked. (See Figure 16.)[26] Because at these high resistances the output would be a series of clicks rather than a tone, measurements would take some time, but with a decade resistance in series with a small rheostat arranged to measure 0 - 1 ohm, extremely accurate resistance measurements could be made. If the unknown resistance is replaced by two small wires used as a microtact, then the difference in resistance between the air and the liquid will be indicated by a jump in frequency when the liquid reaches the level of the microtact. If the unknown resistance is a thermistor, the dial can be calibrated in temperature units, depending upon the function of the particular thermistor used to temperature, and the instrument becomes a thermometer. The unknown resistance is now substituted by a cadmium sulfide or lead selenide photoresistor, and with the calibrated resistance the instrument becomes a quantitative light intensity indicator. Without the calibrated resistance, it would be difficult at best to make quantitative measurements, but we have the light probe which will solve many problems encountered in doing more advanced experimentation.

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[26] Gunderson, Robert, "A Simple Continuity Meter", BRAILLE TECHNICAL PRESS, 1951, p. 37.

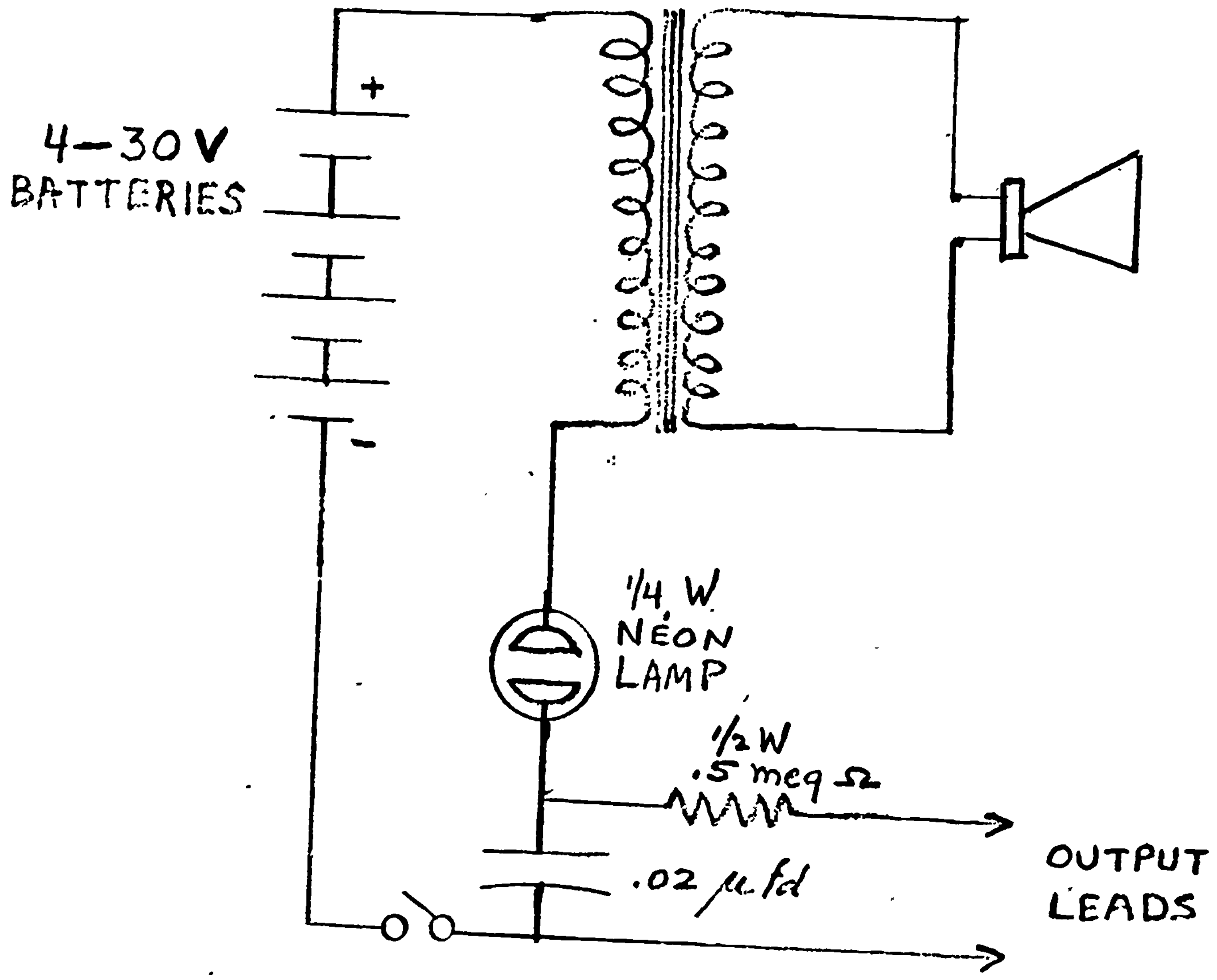

Figure 16. Continuity Checker (from Gunderson, ref. 26).

B. Uses of the Light Probe

Since the results of almost all experiments of any real significance are observed visually; in fact, since so much of the world is observed visually, the most obvious and ultimately most helpful way to help the blind is to convert light signals into signals perceivable by the blind. The obvious light receptor or input for such a system is the photovoltaic cell or photoresistor, and the output is either auditory or tactile. A tactile method for reading stationary oscillographs was being developed by the Technische Hoogeschool of Delft, Holland[27] which consisted of a photo transistor whose light input was the phosphorescence of the screen. The increased current through the transistor was used as part of the input of a servo mechanism driving a pin which traced the oscillograph. However, the further development of this method was discontinued when the student for whom it was intended died.

The most promising developments for use in the laboratory have been done in the field of audification. An early pointer reading device, developed by Witcher and Washington, consisted of two relaxation oscillators, one of which is controlled by a photo resistor in an optical probe, the frequency of the other being controlled by an adjustable resistance.[28] The instrument is calibrated by tuning the adjustable oscillator to zero beat with the photo resistance controlled oscillator, with

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[27] Boiten, Roelf, Letter to writer. Director of Technische Hoogeschool Delft, Holland.

[28] Witcher, C. M., and L. Washington, Jr., MASSACHUSETTS INSTITUTE OF TECHNOLOGY RESEARCH IN ELECTRONICS QUARTERLY PROGRESS REPORTS, #30, July, 1953, p. 54.

the photocell receiving the image of a pointer. The instrument would then be moved along the dial of the meter taking a certain reading until the pointer was found, indicated by a zero beat condition in the loudspeaker. However, it was later found that the second oscillator was superfluous.[29] One could as easily listen for a peak in frequency for a black needle with a shiny background. In an improved version of the instrument of Witcher and Washington, therefore, there was only the light controlled oscillator. Other models employing a change of frequency to indicate the presence of a pointer have employed one and two transistor oscillator and multivibrator circuits and have contained both electronics and a probe in a pen sized casing. One model specifically for reading pointers is equipped with a cylinder containing a lamp for illumination and protruding from the side of another cylinder containing the electronics at the proper angle for the reflected image to be received by the lens.[30]

Wexler's light intensity indicator would appear therefore to be awkward compared to those more sophisticated models, since probe and electronics are separate. The advantage of Wexler's model is that the probe can be disconnected and the oscillator can then be used in the ways mentioned above. Another of the beauties of Wexler's device is its amazing simplicity. The probe is not a lens, but simply a glass rod painted

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[29] Witcher, C. M., and L. Washington, Jr., MASSACHUSETTS INSTITUTE OF TECHNOLOGY RESEARCH IN ELECTRONICS QUARTERLY PROGRESS REPORT, #38, July, 1955, p. 74.

[30] Zimmerman, H. J., Adler, R. B., Mason, S. J., Kruse, J. B., Hurtig, C. R., and Lipsky, A. H., "Sensory Aid with Transistors", MASSACHUSETTS INSTITUTE OF TECHNOLOGY RESEARCH IN ELECTRONICS QUARTERLY PROGRESS REPORT, #42, July, 1956, p. 57.

black except for the tip. The bare photocell can be used in cases of very weak light. This has been used by students of Wexler to observe the moon and to measure its elevation. A "coarse" probe with a tip cross section of about 0.5 mm^2 can be used with ambient light.

In physics, this probe can be used in optical experiments. A circular optical bench developed by Wexler employs two movable rods attached to the center. The object to be studied is also placed at the center of the circle. The rod containing the light source and the specimen to be studied represents the incident wave, and an arm containing the light probe represents the reflected or refracted wave. When the reflected or refracted wave has been found, the two arms can be tightened with a set screw and the angle between them can be measured using the braille degree marks on the rim of the circle.

Outside of physics, this probe has many other uses which are noteworthy. It can be used to locate any source of light such as a window, a lamp or a doorway. It can be used to detect light and dark colored materials. The experiment involving black and shiny objects mentioned above is a good example of this. In titrations with litmus, the probe can be placed in the titration flask and the end point of the titration can be noticed by a sudden shift in frequency of the output signal. This is due somewhat more to the fact that the CdS cell is more sensitive at the red end of the spectrum than at the blue end. With this probe's ability to find light and dark objects, there is some indication that it might even be used as a simple guidance device. However there are complexities involved here not within the scope of this text.

A finer probe, requiring external illumination, is used for accurate pointer reading and possibly for reading of print material. Some blind students have learned to read with a device known as the optophone, the output of which is very similar to that of this light probe, although usually variations in signal as complex as those involved with printed material are beyond most blind readers.

The inference thus far has been that the light probe, when used for detecting pointers, is simply held in the hand and run along the meter dial until the pointer is found, and then the reading can be taken on a transparent braille scale placed over the visual dial. However the problem of magnification comes in here. In fact, the manufacture of a probe was stopped because readings could not be made accurately enough with it.[31] Since a solution of this program was found by Wexler, this action seems regrettable today. Wexler puts the visual meter under a small board upon which a rotatable rod is mounted with its center of rotation along the axis of rotation of the pointer. A lamp is set to illuminate the tip of the pointer. The only modification of the visual instrument which may be made is a sliver of aluminum or a drop of reflective paint on the tip of the pointer on a black background. With some meters this will not be necessary. At the end of the rod is a pointer on a magnified braille scale. A visual meter with a radius of one inch, for example, would require a rod with a pointer four inches from the center to give proper magnification. A pointer which reflects against a black

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[31] Keller, A. S., American Foundation for the Blind, Letter to Writer.

background is preferred since there would be silence in the speaker or earphones until the pointer was found, at which time there would be a signal. In operation, after the reading is taken, the rod is turned until a signal appears in the headset, and the reading is then taken in braille on the magnified scale.

IV. A SURVEY OF LABORATORY METHODS IN SOME SCHOOLS FOR THE BLIND

When the writer left the school for the blind which he had been attending, he believed firmly that a science curriculum in schools for the blind was not only nonexistent but actually discouraged. Although there are science curricula in some American schools for the blind, they are woefully inadequate, since the small number of students interested in such courses would seem to make it unfeasible to put much money into science equipment when it might be used more advantageously elsewhere.

But while in Germany, the writer visited a school for the blind which contained an adequate elementary science curricula. From this, he hoped to find schools in other advanced countries which might have similar or even better curricula. Letters were written to institutes in England, Germany, Israel, Japan, the Netherlands and Sweden. The letters were not formal questionnaires, but in general, the following questions were asked: 1. Do you have a science curriculum, particularly in the field of physics? 2. If so, at what level? 3. Is there a laboratory in your school? 4. If so, what sort of equipment is available? 5. What type of experiments are performed? 6. How in particular are electrical measurements taken and optical experiments performed?

Of the seven letters sent, six were answered. Since the writer knew of no school for the blind in Japan, his inquiry went to the Nippon Tenji Toshokan of Tokyo, from which no reply has been received. However, it was learned from Mr. Wexler that physics curricula are being initiated in the approximately thirty schools for the blind in Japan, and that the government is calling for the manufacture of devices based upon Wexler's principles. A light-intensity indicator of Japanese design involved intensity changes, rather than frequency changes, of its output. The intensity of the output decreased with increased light intensity, a characteristic which both Wexler and the writer found unsatisfactory, but the compactness of the device is highly desirable.

Both the Kungliga Blindtinstitut of Sweden and the Vakok es Csokkenlato Szovetsege of Hungary admitted that there was no existing physics curriculum in the institutions of those countries for the blind. The Swedish reply inferred that there were students successfully studying physics in high schools for sighted students. The Hungarian reply spoke of blind students successfully pursuing the study of mathematics but not physics.

Mr. Roelf G. Boiten of the Technische Hoogeschool of Delft, Holland, mentioned that there was no existing physics curriculum in the Netherlands but referred the writer to the Marburg Blindenstalt of Germany.

At the Jewish Institute for the Blind in Jerusalem, Israel, there is a general science curriculum at the elementary level. As this institute does not include high school, this curriculum is quite commendable, although the way it is taught may be somewhat unsatisfactory. The students are encouraged to set up and examine the apparatus, but no attempt has been made to modify the experiments or the teaching procedure for blind students. Experiments perceivable by blind students are done by the students, but other experiments, such as optical experiments, are not modified but performed by the teacher and explained to the students. Physics subjects taught are the study of air pressure, heat, electricity and some optics.

At the Worcester College for Blind Boys in England, there are two levels of physics curriculum, the ordinary or 0 level for those simply studying high school physics, and an advanced level for those studying to the level of university matriculation. The advanced curriculum, in addition to the ordinary level material, includes extremely sophisticated study of classical mechanics, accoustics, thermodynamics, optics, electricity and magnetism, and electronic circuitry. Laboratory work is considered of fundamental importance, especially at the ordinary level, and all apparatus has been modified in many of the ways described in the preceding sections of this paper.[32] But Wexler, in his visits to this college and Chorley Wood College for Blind Girls (with a physics curriculum at a similar level) found that the actual laboratory layout was not conducive to blind students taking the initiative in experimentation.

The Provinzialblindenanstalt of Soest, Germany, visited by the writer, has somewhat of an elementary science curriculum. Particularly striking to the writer were experiments in electronics using circuit elements mounted in holes in a pegboard and connected with conducting elastic wires.

The Carl-Strehl-Schule in Marburg, Germany, an institute for blind and partially sighted students, contains a "fully normal course of study" in physics but no particular field of physics is mentioned. The laboratory work is mainly based on what improvisations can be made and is still in the beginning stages. The blocking oscillator is used successfully as a continuity checker, ohmeter, ligh-intensity indicator and resistance thermometer. The null method is also used for measurement of

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[32] The reply from Worcester College for Blind Boys stated that apparatus representing wave phenomena, such as the ripple tank, seem to defy modification.

resistance, voltage, current and temperature. A resistance thermometer is used in this latter case in a Wheatstone Bridge-type circuit. A version of the servo-operated meter reader, developed as a demonstration apparatus by Heathkit Corporation and sold under the designation of EV2, is used also for voltage, current and resistance measurements in conjunction with visual meters.

On the surface it would appear that the writer's expectations were fulfilled. Five of the seven countries surveyed indicated physics curriculum, and through the writings of A. Wexler and M. I. Tolozov, some knowledge has been gained of similar curricula in Australia, New Zealand, and the Soviet Union. However, in all cases, the laboratory facilities are primitive at best. There has been progress, and this progress is to be commended. But there is still room for improvement.

V. SUMMARY AND CONCLUSIONS

As a summary, it can be said that although the problems of the blind physicist or physics student appear to be numerous and insurmountable, there are in fact only two unsolved problems. At present, the blind student must use the "brute force" method of asking someone else to read such material to him in order to do even a portion of the necessary reading, and there seems no other immediate solution to this problem. But the future of the laboratory worker, although on the surface equally as grim, can be made easier by the application of several principles. Raised line or indented line diagrams, in combination with some verbal explication, can be used to describe certain apparatus to a blind worker, or by him to communicate a desired circuit or design to a sighted technician. (There is, however, no substitute for actually allowing the blind student or worker to touch and thoroughly examine the apparatus he is to use.)

In conjunction with this is tactilization. In most cases the use of the cutaneous, tactile or balance senses can be used only in demonstration type experiments, but the reading of tactual meters with Brailled scales is and will continue to be of fundamental importance in any experiment involving quantitative measurement.

Due to the inability of the finger to detect the minute distances between two points on a dial of which the eye is capable, it will be necessary to magnify the scale size by a factor of four in order to take the accurate measurements required of the data of higher level experiments. This magnification may be accomplished by the microtact or with a lamp and photocell mounted upon a rod attached at the center of rotation of the meter movement and containing a pointer at its free end which moves over the magnified Braille scale.

Both of the above mentioned methods of magnifying Braille scales (not the only methods, as evidenced by Wexler's micrometer caliper) also employ audification. Audification of apparatus in general involves the use of bells, buzzers and vibrators. However, at the present state of the art, these devices are not only clumsy and inefficient, but should be avoided, particularly in the case of a blind student in a class of sighted students, as they would be extremely annoying. Use should be made instead of electronic devices employing earphones. The best example of this is the relaxation or blocking oscillator in which the frequency can be controlled by the resistance in its circuit. Even in the case of the microtact principle, involving the closing of a switch, the blocking oscillator can be used in place of the bell or buzzer, since the sudden change from an extremely high to an extremely low resistance would produce a sudden tone in the earphone, announcing that contact has been made between the feeler wire and the needle of the meter.

At the high school and beginning college level, the sighted student is supplied with the desired pieces of equipment which he needs for experimentation, and the blind student should have the same privilege. This would involve the general manufacture of instruments employing the principles discussed in this paper. A number of devices for non-technical use are available through the American Foundation for the Blind in New York, but the technically oriented blind man is still forced to rely on his own ability to improvise. The servo-operated meter reader and the attempt of the Japanese government to provide devices for blind science students are definitely steps in the right direction. One device developed for general use has been used with some degree of success by the writer. This is a binary nuclear disintegration counter, employing a Geiger-Muller tube, which gives an audible click every 2^n counts, where n ranges from 0 to 6. The counter was controlled by a timer which was set by a dial with rotary switch positions at each minute. Reset was done automatically at the press of a button. The only difficulty was that with strong sources, a click every disintegration made it impossible to count, due to the rapidity of the click succession. And a click every 2, 4, etc. counts meant a loss of accuracy for the blind student. A visual digital counter was available for sighted users. One solution to this problem could possibly be to record the instrument's clicks on magnetic tape and slow them to a half or a quarter the recording speed, at which speed the clicks could be easily counted, but this procedure would take from three to five times as long as ordinary measurements.

Nevertheless, the above description does suggest a sixth principle which could be used by blind experimenters - automation. In the case of chemical titration, for example, the photo resistance used to detect a color change could be employed in an amplifier circuit which would in turn activate an electric valve which would shut off the flow of the titration solution.

An example outside of the field of physics of how automation may help a blind worker is in the use of a keypunch. Since the statements of a computer program must be located in certain columns, a control card for the keypunch may be used, making it possible to skip automatically to the column in which the statement begins and to release the card if the number of usable columns has been exceeded. A simple convenience to a sighted keypuncher, it may mean the difference between a fast, efficient job and hours of miserable drudgery to a blind worker.

The digital computer, already used in the automation of some advanced experimental work and the processing of data, could easily become the blind worker's most useful tool. Automation of the apparatus could free the blind worker from worrying about the mechanics of actually running the experiment and enable him to concern himself with the more important matters of apparatus design, experiment design or the understanding of the theory behind the experiment. The computer could also facilitate the communication of experimental results to sighted colleagues. There are in existence subroutines which make it possible to graph data. Also the blind worker may find it difficult to type neat looking data tables, but it is not at all difficult for him to tell the computer to do so. Complicated equations may be extremely difficult or even impossible to communicate to sighted colleagues due to the absence of most of the more important mathematical symbols on all but the most expensive typewriters. The present computer languages, however, recognize only the symbols found on an ordinary typewriter. For example, the expression for Centripetal force, $f = mv^2/r$ is much more easily written in computer language, f = m*v**2/r since the need for shifting the typewriter carriage a half space up or down to produce superscripts or subscripts is eliminated.

Communication between the computer and the blind programmer can be accomplished through a subroutine developed at the University of Cincinnati Medical Computing Center which converts all computer outputs into Braille, using the ordinary printer to produce the Braille dots.[33]

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[33] "Computer Work for the Blind", The Staff of the Medical Computer Center, College of Medicine, U. of Cincinnati, pp. 23-28.

With all these possibilities before us, we can see that the field of development of devices for blind students and laboratory workers and the development of better laboratory methods is wide open and challenging. At present, though there seems to be much progress in some shcools for the blind, all is not being done that could be done. There are three things badly needed: First, the publication of Brailled laboratory manuals containing experiments the results of which are perceivable by blind students. Second, the production of laboratory apparatus usable by both blind and sighted workers. And, third, more students and teachers who consider it not a burden, but a challenge, to study and teach physics.

At present, the teaching of experimental physics to the blind is itself an experiment and, at this writing, inconclusive.

APPENDIX I. SOME SIMPLE PHYSICS EXPERIMENTS FOR THE BLIND

In this section, two physics experiments at the high school level[34] will be outlined to illustrate the methods discussed above. Various writers of articles on this subject have made pleas for more and better laboratory manuals written for blind students, and suggestions have been made for the format of such manuals. Until now, these pleas have gone largely unanswered. There are only inadequate braille manuals at high school levels, and the role of the blind student in experiments at the college level and beyond is somewhat unclear even in the mind of the writer. This paper is not intended to be one of the long expected manuals, but possibly the writing up of two experiments, one involving a complete modification of procedure, the other involving only the use of different instruments, but following the same procedure as that outlined in a typical high school manual should give badly needed impetus toward future work.

A. An Experiment for Determining Boyle's Law

The pressure vs. volume relationship of an essentially ideal gas at constant temperature is typically demonstrated using a J-tube opened

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[34] Laboratory manuals at the college level do not give the experimenter such explicit instructions, and since it will be necessary for the experimenter to use his ingenuity somewhat more, the writer has decided not to attempt an exact write-up of an experiment at this level. However, an important conclusion can be reached. That is, if the student is given an active part in experiments at the high school level and even earlier, if there is an elementary physics course in a particular school, he will be adequately equipped to deal intelligently with laboratory work at the college level and beyond.

at one end and containing mercury. The pressure on the volume of gas trapped in the closed end of the tube is calculated from the difference of the heights of the mercury columns in each arm of the tube, and the volume is calculated from the difference between the mercury level in the closed arm and the height of the arm. The difficulty of adapting this procedure to the use of microtact probes is the impossibility of conveniently fitting the closed end of the J-tube with a probe. The experiment could probably be adapted to the use of a light source and photo probe to detect the mercury level in the closed end of the J, but Wexler has devised an extremely simple and ingenious apparatus which will be used in the following experimental write-up.

Determining Boyle's Law

Object: To determine the pressure and volume of a gas at constant temperature.

Discussion: The relationship between the pressure, volume and temperature of an ideal gas is given by the expression: $PV = RT$, where P is the pressure on the gas, V is its volume, R is a constant and T is its absolute temperature. At constant temperature this becomes: $PV = K$, a constant. This law, determined by Boyle and bearing his name means, in words, that at constant temperature, the pressure is inversely proportional to the volume: the larger the pressure, the smaller the volume of gas, and vice versa. This relationship can be determined with the use of a simple bicycle pump.

The cylindrical cross sectional area, A, of the barrel of the pump is constant over its length. If a weight, w, is placed on the top of the pump barrel, a pressure will be exerted on the gas in the barrel equal to w/A + p, where p is the atmospheric pressure read on a barometer.[35] The volume of air in the barrel will be equal to A times the distance from the pointer to the top of the barrel, or the difference between the pointer position and the length of the entire barrel.

Apparatus: Bicycle pump apparatus (see Figure 17), weights.[36]

Procedure: Find the weight of the platform, W, and the cross section, A, of the barrel, unless this information is given to you by the instructor. Find the barometric reading. Read and make note of the pointer position on the barrel scale. Make ten or more other readings, each time adding one or more weights to the platform. Make a data sheet with the following entries:

Test	W (weight of platform)	p (atmospheric pressure)	w (weights added to platform)	v (gas volume)
1				
2				
3				
: 10				

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[35] The barometer pressure may be read by the student using a brailled aneroid barometer or a mercury barometer in conjunction with a photo probe and embossed meter stick, or it may be given by the instructor.

[36] An introduction to the apparatus can be made in the discussion of the theory of the experiment, thus eliminating the need for diagramming. The particular apparatus designed by Wexler was for a class of blind students and used a braille scale embossed on aluminum foil which was then wrapped on the pump barrel and read with a brass rod pointer.

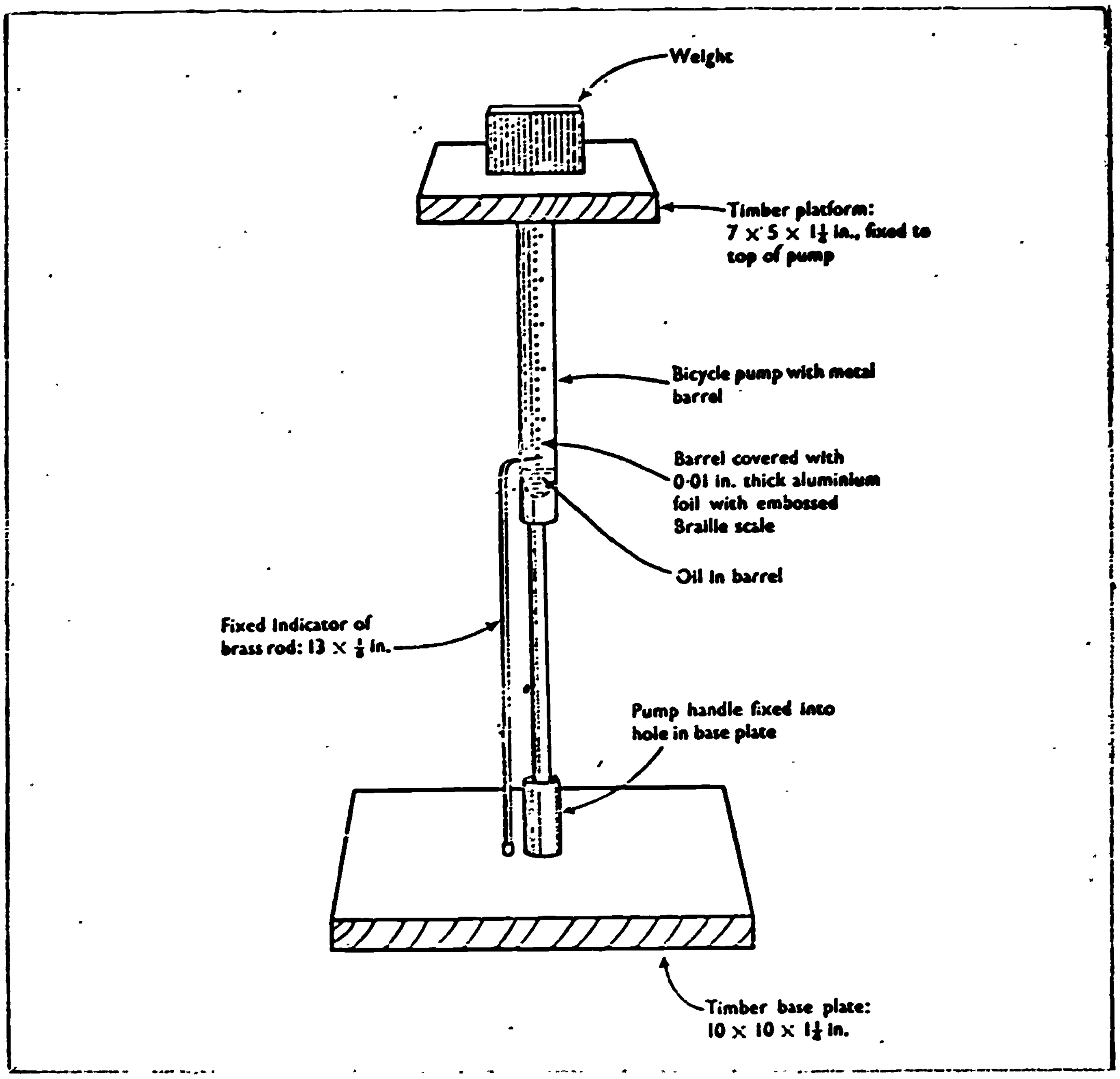

Figure 17. Boyle's Law Apparatus (from Wexler, ref. 15).

Make a graph (using a graph board) with pressure as the abscissa and volume as the ordinate. What kind of curve is formed?

B. An Experiment Determining the Heat of Fusion of Ice

(This is an example of an experiment requiring no procedural modification and the use of only two modified pieces of equipment: the spring balance (see Figure 6) and a thermistor thermometer. The temperature can be measured with a thermistor in conjunction with a battery and an ammeter with a magnified Braille scale, as first designed by Wexler, or in conjunction with a blocking oscillator and a calibrated resistance with a Braille dial calibrated in temperature.)

Object: To determine the amount of heat required to change one gram of ice at $0^{\circ}C$ to liquid at the same temperature.

Discussion: The heat of fusion of a substance is the heat required to convert a gram of the solid substance at the melting point to liquid at that temperature. If ice is placed in a well insulated calorimeter containing a mass of water at or above room temperature and allowed to melt, the temperature of the entire mass of water will decrease until an equilibrium temperature has been reached. The heat lost by the water in the calorimeter will be equal to the heat required to melt the ice plus the heat required to raise the temperature of the melted ice to the equilibrium temperature. If the specific heat of water is a constant equal to 1, then we may write the equation:

$$M(mc + M)(t_2 - t_1) = x + Nt_1$$

where m is the mass of the calorimeter and stirrer, M the mass of water in the calorimeter before adding ice, N the mass of the added ice, t_2 the initial temperature of the water in the calorimeter and t the equilibrium temperature of the mixture. The specific heat of the calorimeter material, c, can be given by the instructor or looked up in a table of specific heats if the material of the calorimeter is known. M, m, N, t_1 and t_2 can be easily measured, and it is only necessary to solve the above equation for x, the total heat required to melt the mass of ice added. The heat of fusion is then x/n, where n, the mass of the ice, is the difference between the mass of the calorimeter and water before and after the ice was added.

Apparatus: Calorimeter with stirrer and thermometer, balance and weights, (possibly spring balance in the case of a blind student), ice, instrument for crushing ice, paper toweling.

Procedure: First weigh the calorimeter and stirrer. Then fill the calorimeter about half full of water somewhat above room temperature and weigh again. The mass of the water is the difference between the mass of the empty calorimeter and stirrer and the calorimeter and water. Measure the temperature of the water[37] in the calorimeter and crush some ice and place this into the

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[37] A more efficient use of the thermistor resistance thermometer would be in conjunction with the blocking oscillator and resistances with dials calibrated for temperature readings. The student would then stir the mixture of ice and water until a steady tone in the earphones indicated the equilibrium temperature at which time he would take the temperature measurement.

calorimeter. Wrap the calorimeter well with several layers of paper toweling and stir, taking temperature readings until equilibrium temperature is reached. Record this temperature in your data sheet. Your data sheet should contain the following information:

Mass of empty calorimeter	Weight of calorimeter and water	Mass of water	Initial temperature of water	Specific heat of calorimeter	Mass of ice	Final temperature after melting of ice

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